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ON THE SPECTRA OF ARGON.

By H. KAYSER.

During the preceding summer I published a part of the blue spectrum of argon,[1] in the expectation that the red spectrum, as well as the rest of the blue spectrum, would shortly follow. It was unfortunately impossible to carry out my plan, for several reasons, the principal of which was the unsuitability of the conditions at the Physical Institute at Bonn. The building is situated at the corner of two of the busiest streets in the city, and the traffic gives rise to such vibrations within the rooms that it is impossible to carry on any investigations with apparatus requiring perfect stability of adjustment.

In parts of the spectrum for which an exposure of half an hour was sufficient, I succeeded in making fairly good progress, although many of the plates were poor; but when exposures of from two to three hours became necessary, the probability that the grating would remain so long undisturbed by tremors, and consequently give sharp spectra, became much less. In fact, I often exposed twelve or more plates before a serviceable negative was obtained. Frequently I was on the point of giving up the work altogether, as impossible of execution at Bonn, when a successful plate would encourage me to continue. In the parts of the spectrum with shortest wave-lengths, *i.e.*, above λ 3000, and in the red, yellow and green, an exposure of even three hours is not sufficient to obtain all the lines. With exposures of from four to eight hours I have indeed obtained negatives of the spectrum, but they were all so blurred that measurement of the spectral lines was quite out of the question.

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[1] *Chem. News*, 72.

Thus I was finally compelled to abandon the complete investigation of the argon spectrum, and I here give the results for such parts of the spectrum as I was able to obtain under the unfortunate circumstances already alluded to.

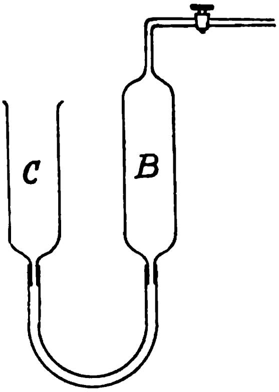

FIG. 1

The argon was obtained from air in the known manner, by causing the air, after it had been freed from CO_2, H_2O and O, to pass several times over glowing magnesium. The resulting gas contained about 60 per cent. of argon, and I am greatly indebted to Dr. Bettendorff for twice preparing a considerable quantity of it in this purified condition. It was introduced into a vessel, the form of which is shown in the accompanying figure. *B* contains about 400 cubic centimeters; on its upper side it has a capillary tube, bent at a right angle, and provided with a stopcock. Two electrodes are sealed into the glass, leaving a striking distance between them of from six to eight millimeters. The tube is graduated. On the lower side it is connected with the open vessel *C* by means of rubber tubing. Both vessels having been filled with caustic potash, impure A and then an equal volume of O are admitted by the cock, and then the spark from an induction coil is passed through the mixture of gases. NO_2 is formed, and absorbed by the caustic potash. At first the volume diminishes very rapidly, then more slowly, and finally no more change occurs. I have always allowed sparks to pass until no further contraction was perceptible in the last twenty-four hours. The O was obtained electrolytically from water acidulated with phosphoric acid, and at the end of the operation it was always my custom to admit 20^{cc} to 30^{cc} of electrolytic hydrogen and produce an explosion, in order to convert any carbon compounds that might be present into CO_2, and thus to eliminate them.

The vessel *C* was then lowered and freed from caustic potash, while *B* was slightly warmed, and thereby some additional fluid was driven out. A small quantity of a solution of pyrogallic acid was placed in *C*, and drawn over into *B* by warming the latter, in order to absorb the superfluous oxygen. After twenty-four hours the capillary tube was connected with the mercury air pump, in connection with which was also a vessel *D* containing phosphoric anhydride. This vessel was exhausted, while the glass was strongly heated, to about $0^{mm}.001$, and finally, by opening the cock, the argon was transferred from the vessel *B* to *D*, from which it was drawn whenever required for filling Geissler tubes.

In spite of all these precautions I have not always succeeded in obtaining argon perfectly pure. Traces of N and C were often present, although, at the low pressure which is most favorable to the production of the argon spectrum, they were not troublesome. Traces of the bands of cyanogen and nitrogen also frequently appeared in the ultra-violet.

Two forms of Geissler tubes were used. For the visible spectrum the form was the usual one of a capillary tube joining two larger tubes in which were sealed aluminium electrodes. For the shorter wave-lengths, which are strongly absorbed by glass, I used a form which is essentially that of V. Schumann, to whom I am indebted for information regarding the details. The figure gives a view of the front part of the tube in natural size. *A* is a quartz stopper, with plane and parallel ends which are perpendicular to the optical axis. Its conical surface is unpolished, and is ground to accurately fit the neck of the tube. Before the stopper is inserted, a very little grease is rubbed on its outer end, and during the pumping the external pressure drives the grease somewhat further inward, but the inner half of the stopper remains dry, and no vapor from the grease enters the tube. The electrode has the form used by Ames—that of a cylindrical roll of aluminium foil, the view being unobstructed along the axis. The other half of the tube has a similar electrode, and is provided with a small lateral tube for admitting the gas.

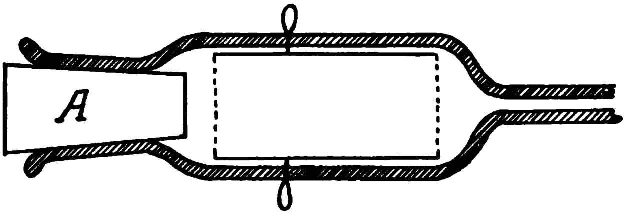

FIG. 2

Great difficulties are encountered in working with argon tubes, since after some use the gaseous contents invariably disappear, particularly when the red spectrum is produced. It is well known that when electrodes are made of platinum, the metal is disintegrated, and is deposited in the form of a mirror on the inner surface of the tube, while with aluminium this unpleasant action does not generally occur. But in argon aluminium also is attacked. As soon as the action takes place, the gaseous contents begin to disappear, the glass begins to fluoresce, and finally the discharge will no longer pass. If the electrodes are thin ($0^{mm}.5$), this final result is seldom reached, since before it can happen the electrodes become white hot, melt, and the tube breaks. In later experiments I therefore had the electrodes made with a thickness of from two to three millimeters, and I have thought that with the smaller heating effect the disintegration of the surface of the electrode and the rate of disappearance of the gas have also been diminished. The action nevertheless occurs, even with the large cylindrical electrodes. What becomes of the vanished argon—whether it forms a combination with the dispersed aluminium or is merely absorbed by it—I have not been able to ascertain; it is at any rate not liberated again by heating the aluminium deposit. Neither have I been able to determine the conditions on which depend the very different lasting qualities of the argon tubes. Many of the tubes become unserviceable after only two or three hours' use; others last as long as forty or fifty hours. These circumstances materially increase the difficulty of the investigation. Altogether I have had to fill as many as fifty different tubes.

It was shown by Crookes that the red spectrum of argon is produced when the ordinary discharge is sent through the tube, and the blue spectrum when a condenser is connected with the induction coil and the spark made to traverse a break in the circuit. In general this statement is correct when the pressure is about two millimeters, which is the pressure most favorable to the production of the red spectrum; but at a smaller pressure the blue spectrum can be obtained without a Leyden jar and interruption in the circuit, and with them, at a higher pressure, the red. In general, therefore, both spectra are seen together, even at the favorable pressure of two millimeters, unless the intensity of the discharge is properly regulated. It is much easier to obtain the blue spectrum pure, *i. e.*, free from lines of the red spectrum, than the reverse condition; for the red spectrum the current must be more exactly regulated to suit the pressure of the gas, but by doing this it is possible to obtain the red spectrum quite pure, and most of my plates show no trace of even the strongest lines of the blue spectrum.

The discharge was furnished by an induction coil capable of giving a fifteen-centimeter spark, the primary current of from eight to twelve ampères being derived from four to eight storage batteries arranged in series.

The spectra were obtained with the aid of a concave grating of the largest kind, belonging to the Berlin Academy of Sciences. Its aperture is six inches and its radius of curvature 6.5 meters. The tubes were placed close to the slit-plate, with the capillary bore parallel to the slit, except in the case of the quartz-stoppered tubes, which were of course so placed that the capillary bore was perpendicular to the slit-plate. In order to give the means of determining wave-lengths, iron electrodes were also placed diagonally in front of the slit, the spark between them being produced by a second induction coil. Both sources of light were kept in action during the whole time of exposure, and I believed that a relative displacement of the iron and argon spectra was in this way made quite impossible. Unfortunately this assumption turned out to be erroneous. Different plates showed that the argon lines were displaced with reference to the iron lines, sometimes toward the red and sometimes toward the violet, the displacement sometimes amounting to as much as 0.2 Ångström units.

This circumstance I explained in the following manner: Let us suppose that the two sources of light in front of the slit are not quite correctly adjusted, but are so placed that the first illuminates only one-half of the grating and the second the other half. If both sources emitted the same wave-lengths, the images formed by the two halves of the grating would nevertheless exactly coincide, provided the photographic plate were exactly in the focal plane of the grating. But if the plate is displaced inwards or outwards two lines arise, which become more blurred and the distance between the centers of which becomes greater, the more the plate is displaced from its proper position. The lines exchange positions, right and left, whenever the true focal plane is passed. According to this explanation the distance A between the centers of the images is related to the error B of the adjustment of the plate as half the breadth of the grating G is to the radius of curvature R; or $A = \frac{BG}{R}$. If the sources of light were still more incorrectly placed, so that, for instance, only the first and last third of the grating were illuminated by them, *G* would be equal to two-thirds of the grating width, etc. Now, I have attempted to ascertain by experiment how great *B* can be made in practice without producing a perceptible falling off in the sharpness of the lines. The result shows, I believe, that an error of adjustment of 1^{mm} cannot be observed when the grating is fully illuminated, and that with errors of even 2^{mm} and 3^{mm} the plates are still serviceable. If, however, the grating is not fully illuminated, the cone of rays becomes narrower, the lines therefore much sharper, and serviceable plates will be obtained with even twofold or threefold greater values of *B*. For my grating the breadth is 140^{mm}, and $R=6500^{mm}$. Assuming that the two halves or the two outer thirds are illuminated, a displacement of 0.2 tenth-meters ($0^{mm}.1$ on the plate) would require values of *B* respectively equal to 9^{mm} and $6^{mm}.5$, which are certainly improbably large, but not impossible. Most of the displacements that I have observed are at most only half as great as that assumed above, and thus are quite well explained in this manner.

In their researches on the spectrum of clèveite gas, Runge and Paschen[1] have observed similar displacements, which they ascribe to the astigmatism of the image, and which they seek to avoid by causing both sources of light to illuminate the same short length of slit. In fact, if we suppose that the slit is somewhat curved, and that 1^{cm} of it is illuminated by one of the sources, while a length of 1^{mm} is illuminated by the other, the image of the first source will be displaced, since every point of the slit is represented by a line 15^{mm} or 20^{mm} long in the image. Nevertheless I find it impossible to accept this explanation in the case of the displacements which I have observed, since it would imply very bad definition of the lines. If the middle of a line as measured were 0.2 tenth-meters out of place, the breadth of the line would be increased by 0.4 tenth-meters; *i.e.*, the line would be greatly blurred, which was not the case in my experiments. However, it is quite probable that the explana-

[1] *Ap. J.*, 3, 6, 1896.

tion of Runge and Paschen, which is undoubtedly theoretically correct, applies to the extreme cases which I observed, so that the error of adjustment was not necessarily so large as the value computed above.

I have considered these circumstances so fully, because they are of fundamental importance in connection with the exact measurement of gaseous spectra. The difficulties vanish when the sources of light are so broad that the whole grating is illuminated. For this reason the method used by Kayser and Runge, of forming an image of the Geissler tube on the slit by means of a lens, is greatly to be recommended, as the more divergent cone of light so obtained completely fills the aperture of the grating. However, only a few of my latest photographs were obtained in this manner.

After I had ascertained the cause of these appearances, I adjusted the plate with the greatest care, and placed the iron spark and Geissler tube in such positions that the grating was fully illuminated. Results were then obtained which were in excellent agreement, and which I regard as correct. The plates with displaced lines thereupon became available, since the wave-lengths could be corrected by the addition of a constant. A beautiful confirmation of the correctness of the wave-lengths was also found; on a plate taken with a quartz tube the two aluminium pairs at λ 3961, 3944 and λ 3092, 3082 appeared among the argon lines, and their deduced wave-lengths agreed with the measures of Rowland.[1]

As normal lines were exclusively used lines measured by Rowland. An idea of the accuracy which was attained can best be formed with the aid of the separate measures for a number of lines. I select for this purpose the strongest group in the red spectrum.

λ 4158.734, 692, 736, 716, 711, 690, 715, 733, 719, 700, 711, 708, 700, 713, 717.

---

[1] This presence of the aluminium lines seems to me to be of interest on other grounds, since I do not know of any case in the literature of the subject where the lines of the electrodes are visible in the spectra of Geissler tubes. Perhaps the lines of other metals may also be obtained in argon, thus allowing the determination of their wave-lengths at low pressure.

λ 4162.941, 866, 904, 885, 933.

λ 4164.309, 323, 317, 281, 293, 293, 316, 326, 327, 319, 314, 309, 306, 295, 292.

λ 4182.007, 997, 010, 977, 978, 993, 022, 017, 000, 971, 017, 012, 000, 009, 011.

λ 4190.846, 831, 868, 853, 844, 830, 824, 853, 838, 821, 857, 824, 841, 838, 851, 838.

λ 4191.168, 194, 167, 149, 126, 146, 163, 149, 193, 151, 183, 162, 153, 171, 162.

λ 4198.452, 443, 457, 420, 435, 414, 433, 463, 424, 419, 443, 432, 440, 433, 432, 441.

λ 4200.814, 781, 802, 790, 796, 767, 802, 830, 765, 782, 785, 802, 800, 804, 791, 807.

In the following table I give for each line the number of observations of which the mean is taken, and the mean error.

In the red spectrum I have only been able to completely photograph the region between the wave-lengths 3319 and 4792. The spectrum has only a few lines of short wave-length, which I have measured on rather poor plates, so that the mean error may be about 0.1 tenth-meter. Above λ 2967 I have obtained no argon lines in the red spectrum; on one tolerably sharp negative made with seven hours' exposure and a very strong current appear only the silicon lines and the mercury line λ 2536. Of the lines having a greater wave-length than 4702 I have several times obtained only the strongest, as far as λ 5912, on plates with sharp definition, and I therefore give the wave-lengths to only 0.01 tenth-meter.

Since the remaining red, yellow and green lines were required for my investigation of the spectrum with reference to the law governing the distribution of the lines, I sought to determine their wave-lengths by means of a plane grating and a spectrometer, and these measures are included in the list, although the results are given to the nearest 0.1 tenth-meter only. They are means of three or four measures, which generally agreed to within 0.1 tenth-meter. The photographically determined lines in the first and second orders were used as normal lines for computing the results of the visual measures.

My photographic measurements in the stronger blue spectrum extend from λ 2762 to λ 5145, although the shortest wave-lengths are deficient in accuracy, as they were measurable on only one or two plates. Here also the few lines lying still further toward the red were supplied by ocular measures.

The measurements of the spectra of argon which have hitherto been published were made by Crookes,[1] with a prism spectroscope, and by Eder and Valenta,[2] with a small concave grating, but in neither of these investigations is the blue divided from the red spectrum. Crookes gives many lines as common to both spectra; Eder and Valenta give the red spectrum between λ 3319 and λ 5060, and designate a number of lines as occurring in the blue spectrum also. I have included in the following list the measures taken from both papers, for comparison with my own. The first column in the table contains the wave-length, the second the approximate intensity, 1 representing the faintest and 10 the strongest line; the third column gives the number of observations, the fourth the mean error, the fifth and last the measures of Eder and Valenta (E) and of Crookes (C).

A comparison of my results with those of Eder and Valenta reveals a very satisfactory agreement; the differences rarely exceed a few hundredths of a tenth-meter, and this may probably be regarded as the highest accuracy attainable with a grating of $0^m.75$ radius, such as was used by Eder and Valenta. The errors in Crookes' work are naturally much greater; they reach several tenth-meters. Some of the striking differences are the following: Crookes has in the red spectrum the lines λ 3904.5, intensity 8, and λ 5746, intensity 6, which do not occur at all in my table. Eder assigns to the line λ 3900.04 the intensity 8, while I have given it the intensity 1. In the blue spectrum Crookes gives a line λ 4938 with intensity 10, which, according to my observations, does not exist; Runge and Paschen also have not seen this line.

---

[1] *Chem. News*, 71, 58, 1895.

[2] *Anzeiger Wien. Akad.*, 21, 1895.

I. RED SPECTRUM OF ARGON.[1]

λ	Intensity	No. of Obs.	Mean Error		λ	Intensity	No. of Obs.	Mean Error	
2967.35	5	1	100		3567.789	4	10	007	3567.84 E 3566.5 C
2968.39	2	1	100		3572.416	2	6	009	3571.89 E
2972.60	1	1	100		3599.822	1	2	036	
3021.52	4	1	100		3606.677	5	11	012	3606.77 E 3605.0 C
3125.70	4	2	030		3632.766	3	9	015	3632.83 E 3632.5 C
3131.90	2	2	010		3634.586	3	8	013	3635.60 E
3175.11	1	1	100		3643.227	2	5	011	3643.27 E
3244.51	1	1	100		3650.258	2	14	018	3649.95 E
3295.44	2	1	100		3654.962	1	6	017	
3302.50	3	2	020		3659.632	2	9	007	3659.70 E
3303.08	1	1	100		3663.392	1	5	010	
3319.459	3	4	005	3319.35 E	3670.783	2	9	007	3670.81 E
3325.626	2	4	027		3675.353	1	6	007	3675.38 E
3341.637	1	2	009		3691.001	2	9	007	3691.07 E
3360.146	1	4	045		3696.587	1	6	030	3696.66 E
3373.586	2	4	018	3373.64 E	3738.030	1	2	003	3738.03 E
3381.573	1	2	054		3743.808	1	2	015	3743.89 E
3387.698	1	2	036		3770.440	3	10	019	3770.81 E 3771.5 C
3388.464	1	2	015		3775.476	1	2	018	3775.62 E
3389.955	1	2	015		3781.461	2	9	010	3781.46 E
3392.885	2	2	009	3392.99 E	3801.049	1	2	018	
3393.848	3	6	005	3393.90 E	3834.768	4	8	010	3834.83 E 3835.5 C
3398 016	1	2	005		3850.693	1	3	030	3850.70 E
3406.287	1	2	018		3866.353	1	2	007	3866.44 E
3442.640	1	2	036		3894.795	2	3	015	3894.76 E
3455.076	1	2	009		3900.065	1	2	026	3900.04 E
3461.192	3	6	006	3461.21 E	3947.645	4	12	010	3947.70 E
3476.894	1	2	005	3476.94 E	3949.107	6	13	007	3949.13 E 3948.5 C
3493.435	1	2	030		4044.565	7	16	006	4044.56 E 4044.0 C
3506.650	2	6	021	3506.59 E	4046.027	2	2	036	4046.01 E
3509.934	1	2	036		4046.620	2	4	015	
3514.513	1	2	060	3514.67 E	4054.663	2	7	021	4054.68 E
3545.947	1	3	016	3545.87 E	4154.657	2	4	009	4156.6 C
3554.435	5	11	007	3554.47 E 3554.5 C	4158.722	9	15	004	4158.63 E 4159.5 C
3556.135	2	4	005	3556.16 E	4162.906	1	5	014	
3559 601	1	3	036	3559.66 E	4164.309	5	15	004	4164.36 E 4164.5 C
3563.362	3	9	018	3563.46 E 3562.8 C	4182.002	5	15	004	4182.07 E 4183.0 C
3564.423	3	9	007	3564.48 E	4190.841	5	16	003	4190.76 E 4191.5 C

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[1] In accordance with the resolution of the Editorial Board of THE ASTROPHYSICAL JOURNAL, this table is arranged so that it begins with the short wave-lengths. In my opinion, however, the choice is a very unfortunate one. Series in spectra invariably run from red toward blue, the numbers determining the order of pairs and triplets increasing, and the intensity diminishing in this direction. Hence the table would naturally run in the reverse direction; for example, the hydrogen spectrum naturally ends with *Hα* instead of beginning with it. While there is yet time it may perhaps be advisable to alter this decision.

λ	Intensity	No. of Obs.	Mean Error		
4191.841	5	16	005	4191.15 E	
4198.162	5	15	003	4198.42 E	4198.0 C
4200.799	9	16	004	4200.76 E	4201.0 C
4205.007	1	4	012		
4251.329	3	8	008	4251.25 E	4251.5 C
4259.491	7	14	006	4259.42 E	4259.5 C
4266.425	5	14	006	4266.41 E	4266.0 C
4272.304	6	14	005	4272.27 E	4272.0 C
4300.249	6	13	005	4300.18 E	4300.5 C
4304.033	1	2	030		
4333.714	6	13	005	4333.64 E	4333.5 C
4335.491	4	11	006	4335.42 E	
4345.322	4	11	006	4345.27 E	4345.0 C
4363.970	1	3	015	4363.93 E	
4510.851	5	8	018	4510.83 E	4509.5 C
4522.389	3	4	018	4522.45 E	4514.0 C
4596.205	3	4	008	4596.25 E	4594.5 C
4628.623	3	3	010	4628.66 E	4629.5 C
4702.504	4	3	039	4702.38 E	4701.2 C
4732.4	1				
4738.2					
4768.3	1			4768.80 E	
4807.8	3				
4849.9	1				
4882.3	2				4879 C
4889.4	1			4888.27 E	
4969.6	1				4965.5 C
5010.4	2				5012 C
5051.3	1				
5063.2	2				5065 C
5120.0	1				
5152.7	3				
5162.6	4				5165 C
5188.46	5	2	016		5185.8 C
5221.9	2				5222 C
5254.4	2				5258 C
5275.3	1				
5412.8	1				
5421.9	2				5421 C
5442.1	1				5444 C
5451.87	3	2	020		5456 C
5458.2	1				
5496.02	4	5	031		5496.5 C
5506.7	1				5501 C
5525.2	1				5520 C
5558.80	5	3	080		5557.0 C
5572.71	3	2	010		5567 C
5581.3	1				
5589.4	1				
5599.6	1				
5606.84	5	3	030		5610 C
5650.90	4	2	010		5651 C
5659.4	1				
5683.0	1				5683 C
5690.1	1				
5772.5	1				5771 C
5802.4	1				5803 C
5832.3	2				5834 C
5860.6	2				5858 C
5882.78	2	2	020		
5888.93	3	2	041		5887 C
5912.22	4	2	025		5909 C
5928.5	2				5926 C
5943.5	1				
5987.5	1				
5999.5	1				
6013.6	1				
6025.8	1				
6031.5	5				6038 C
6043.0	4				6045 C
6052.7	2				
6059.5	4				6056 C
6098.8	1				
6106.1	2				6099 ? C
6145.6	2				6143 C
6155.2	1				
6170.3	1				
6172.9	2				6173 C
6212.5	2				6210 C
6217.5	1				
6296.8	2				6302 ? C
6307.8	1				
6368.0	1				
6384.5	2				6377 ? C
6415.2	5				6407 C
6676.5	3				6664 C
6752.7	3				6754 C
6786.5	1				
6870.6	1				
6937.8	1				
6964.8	8				6965.6 C
7029.2	1				
7066.6	7				7056.4 C
7146.8	1				
7271.6	1				7263 C
7383.9	2				7377 C
7503.4	2				7506 C
7515.1	2				
7635.6	2				7646 C
7723.4	2				

2. BLUE SPECTRUM OF ARGON.

λ	Intensity	No. of Obs.	Mean Error		λ	Intensity	No. of Obs.	Mean Error	
2762.11	3				3210.678	1	2	027	
2774.90	1				3212.737	1	2	015	
2796.66	2			2794.4 C	3222.183	1	2	004	
2824.47	1			2830.2?C	3236.812	1	2	016	
2842.88	2				3237.920	1	2	021	
2853.27	1				3243.845	4	4	013	
2855.29	3				3245.638	1	3	018	
2878.79	2				3249.972	4	4	014	
2884.24	5				3251.888	3	3	005	
2891.73	2				3263.722	2	4	010	
2896.91	1				3263.953	1	3	008	
2924.68	1				3271.122	1	3	033	
2931.52	2			2929.6 C	3273.476	1	3	012	
2942.94	5			2942.7 C	3281.867	3	4	010	
2955.37	2				3282.661	2	3	005	
2979.16	4			2978.6 C	3285.913	8	4	004	
3000.63	2			2998.2 C	3289.201	2	3	009	
3002.67	4				3293.768	4	3	010	
3024.078	3	2	021		3298.652	2	3	010	
3027.181	1	2	012		3301.938	7	4	007	
3029.015	2	2	021		3305.249	2	3	005	
3031.759	1	2	009		3305.720	1	3	010	
3033.620	2	2	009		3306.499	1	3	010	
3039.477	1	2	050		3307.368	3	3	008	
3046.130	1	2	005		3308.040	1	3	016	
3048.552	1	2	027		3311.318	6	4	007	
3054.846	3	2	010		3314.622	1	2	027	
3064.830	2	2	012	3064.7 C	3323.671	2	2	006	
3066.998	1	2	005		3327.441	1	2	012	
3078.212	2	2	005		3332.972	1	2	005	
3083.720	1	2	005	3084.8?C	3336.269	6	3	010	
3093.478	3	2	005	3092.7 C	3339.602	1	2	012	
3110.441	1	2	005		3341.518	1	2	012	
3116.162	1	2	006		3342.532	1	2	012	
3125.980	1	2	005		3344.857	6	3	010	
3127.996	1	2	008		3348.161	1	2	006	
3139.156	3	2	004		3351.112	3	3	005	
3157.577	2	2	004		3352.248	2	2	005	
3161.519	3	2	009		3355.298	1	2	006	
3165.480	1	2	005		3358.633	6	3	005	
3169.812	4	2	006		3361.418	2	2	008	
3171.767	1	2	024		3361.973	1	2	008	
3181.174	3	2	007		3365.660	1	3	015	
3183.171	1	2	012		3366.758	1	3	015	
3187.970	1	2	005		3371.077	1	2	018	
3194.400	1	2	004		3376.618	3	2	008	
3196.109	1	2	015		3379.674	1	2	034	
3204.469	2	2	012		3388.706	4	3	019	3388.0 C

λ	Intensity	No. of Obs.	Mean Error		λ	Intensity	No. of Obs.	Mean Error	
3391.959	4	3	019		3548.680	2	7	018	
3404.432	1	2	015		3555.107	1	2	021	
3413.665	1	2	008		3556.167	1	2	022	
3417.608	1	2	008		3557.029	1	2	022	
3421.821	2	3	011		3558.670	1	2	022	
3424.385	1	2	009		3559.695	8	9	009	3559.66 E 3558.2 C
3429.846	1	3	027		3561.213	7	9	006	3561.13 E 3560.0 C
3430.650	1	4	013		3562.388	1	2	009	
3438.174	2	2	009		3563.198	1	2	009	3563.46 E
3445.254	1	2	010		3564.586	1	2	045	
3450.223	1	2	006		3565.221	2	8	006	3564.0 C
3454.298	2	5	010	3453.5 C	3573.290	1	2	045	
3455.572	1	2	006		3576.808	8	10	007	3576.79 E 3575.0 C
3464.364	2	5	020		3579.000	1	2	015	
3466.533	2	5	018		3580.439	1	3	009	
3471.443	1	2	018		3581.802	4	10	007	3581.83E } 3580.3C
3472.713	1	2	018		3582.547	7	10	007	3582.51E
3473.368	1	2	006		3585.203	1	4	045	
3476.926	5	6	005	3476.94 E 3475.7 C	3586.122	1	2	030	
3478.410	2	6	006		3587.122	1	2	030	
3480.636	5	6	006		3588.633	9	9	007	3588.58 E 3587.0 C
3484.121	1	2	012		3592.198	1	5	031	
3488.316	1	4	021		3603.981	1	2	015	
3491.030	2	5	012		3606.056	2	8	010	3605.0? C
3491.440	5	6	010	3490.0 C	3622.354	2	7	010	3617.5? C
3491.723	7	6	006	3491.71 E	3637.212	1	3	010	
3493.562	1	2	005		3638.015	7	10	010	3631.7? C
3495.193	1	4	015		3640.022	2	9	007	
3497.219	1	2	033		3650.313	1	2	024	
3498.419	1	3	045		3651.141	1	7	030	
3499.815	3	5	008		3655.474	3	9	005	
3500.724	1	2	006		3656.270	1	9	022	
3502.841	2	4	008		3660.635	1	9	009	
3503.730	2	7	008		3669.700	1	5	044	
3506.426	1	2	009		3670.071	1	2	015	
3507.268	1	2	008		3678.478	2	8	008	
3507.795	1	2	015		3680.124	1	6	030	
3509.475	3	6	010		3692.739	1	4	021	
3509.961	3	6	010		3696.160	1	2	022	
3511.286	8	6	005	3508.8?C	3710.167	1	2	024	
3511.804	1	4	010		3712.941	2	4	024	
3514.351	4	4	008	} 3514.67E 3513.5C	3714.744	1	3	024	
3514.576	4	5	016		3716.704	1	4	024	
3518.079	1	4	036		3717.367	1	8	017	
3520.191	3	7	012	3519.2 C	3718.403	3	11	005	3718.39 E 3718.0 C
3521.431	2	7	015	3520.5 C	3720.617	1	10	010	
3522.100	1	6	019		3724.697	2	7	027	
3535.514	3	6	012	3534.3 C	3725.665	1	4	060	
3545.792	5	7	016	3545.87 E 3544.5 C	3729.450	9	12	007	3729.44 E 3729.8 C
3546.005	5	7	021	3546.07 E 3547.5?C	3733.122	1	2	014	

λ	Intensity	No. of Obs.	Mean Error		
3735.542	1	2	048		
3738.094	3	11	004	3738.03 E	3738.5 C
3747.135	1	2	039		
3750.428	1	3	010		
3753.722	1	8	019		
3756.541	1	4	012		
3763.715	3	9	008		
3765.463	5	12	006	3765.43 E	3766.0 C
3766.286	2	11	012		
3770.719	2	10	010	3770.81 E	3770.5 C
3776.885	1	3	010		
3781.018	6	12	004	3781.07 E	3780.8 C
3786.536	2	10	015		
3795.509	3	9	009		
3796.882	1	3	036		
3799.596	2	9	015		3799.5 C
3800.429	1	3	060		
3803.381	2	9	006		3803.5 C
3808.746	1	6	015		
3809.649	3	9	005	3809.58 E	3809.5 C
3819.300	1	3	093		
3825.865	1	5	020		
3826.976	3	10	008		3827.5 C
3830.585	1	6	040		
3841.709	1	5	015		
3844.921	1	6	014		
3845.535	1	6	016		3845.5 C
3846.860	1	3	006		
3850.715	8	11	006	3850.70 F.	3851.5 C
3854.522	1	3	042		
3855.366	1	2	033		
3856.210	1	4	034		
3858.456	2	6	009		
3868.718	6	11	007	3868.68 E	3868.5 C
3872.326	2	7	013		3871.8 C
3874.288	1	3	040		
3875.406	3	10	008		3875.5 C
3880.432	1	4	039		
3891.550	2	8	009		
3892.128	4	9	009	3892.10 E	3892.0 C
3900.763	2	8	022		
3907.896	1	2	090		
3911.721	1	6	022		
3914.931	3	9	018	3914.93 E	3915.0 C
3924.798	1	2	035		
3925.903	3	8	009	3925.98 E	3927.5 C
3928.749	7	11	009	3928.82 E	3928.5 C
3931.382	2	9	016		
3932.717	4	9	008	3932.71 E	3931.8 C
3937.208	1	3	039		
3944.409	4	9	005		3943.5 C
3946.290	4	10	009		
3952.892	1	6	013		
3958.529	2	3	013		
3960.591	2	7	021		
3968.496	4	11	006	3968.54 E	3967.8 C
3974.646	2	7	021		
3974.859	1	2	018		
3979.541	3	11	009		3978.5 C
3988.378	1	5	018		
3992.196	2	10	008		
3995.035	1	2	060		
4010.052	1	2	030		
4011.527	1	2	045		
4014.002	6	12	006	4013.97 E	4013.0 C
4017.986	1	2	015		
4023.730	1	3	044		
4034.022	2	9	010		4033.0 C
4035.624	2	9	006		
4038.966	2	8	010		
4043.039	4	12	009	4043.02 E	4044.0 C
4053.111	1	5	010		
4068.171	1	2	045		
4072.159	7	11	007	4072.15 E	4072.5 C
4072.579	3	9	010		
4076.854	2	6	012		
4077.204	2	5	015	4077.47 E	
4079.712	2	9	010	4079.83 E	
4080.872	1	2	027		
4082.535	2	9	012	4082.59 E	
4089.041	1	3	021		
4097.265	1	2	090		
4099.602	1	2	018		
4104.107	7	10	016	4104.10 E	4105.0 C
4112.916	1	5	039		
4131.913	4	7	009	4131.95 E	4131.5 C
4146.761	1	2	030		
4156.295	2	6	013		
4178.504	1	2	027		
4179.479	1	4	003		
4183.106	2	3	019		4183.0?C
4189.774	1	2	022		
4202.106	2	4	015		
4203.609	1	4	036		
4218.843	3	5	006		
4222.839	3	6	015		
4227.146	2	4	018		
4228.310	5	8	007	4228.30 E	4228.5 C
4229.015	1	2	036		
4229.813	1	2	063		

λ	Intensity	No. of Obs.	Mean Error		
4237.395	3	6	010		
4266.684	6	9	006	4266.41 E	4266.0 C
4275.327	1	4	014		
4277.718	6	8	004		4277.0 C
4283.054	3	7	015		
4298.222	1	2	015		
4300.824	2	7	012		4299.0 ?C
4309.311	2	7	020		
4331.354	6	10	007	4331.31 E	4333.5 C
4332.205	3	9	005	4332.15 E	
4337.244	1	3	015		
4343.904	2	5	013		
4348.222	10	9	007	4348.11 E	4348.5 C
4352.368	4	9	007		
4362.229	2	5	018		
4367.952	1	5	033		
4370.928	4	9	009	4370.89 E	4369.0 C
4371.504	4	9	009	4371.46 E	
4375.201	1	3	090		
4376.112	3	6	030	4376.15 E	
4379.827	6	9	005	4379.79 E	4376.5 C
4383.900	2	2	020		
4400.271	3	7	003	4400.20 E	4399.5 C
4401.156	5	9	006	4401.17 E	
4408.095	1	3	012		
4421.113	1	6	015	4421.06 E	
4426.165	9	9	005	4426.15 E	4422.5 C
4430.355	6	9	006	4430.35 E	4426.5 C
4431.172	4	9	005	4431.13 E	
4434.037	2	6	018		
4439.539	1	4	030		
4443.545	1	2	005		
4449.123	2	4	013		
4460.682	2	4	036		
4475.015	2	4	019	4475.15 E	
4482.003	5	6	015	4482.03 E	4478.3 C
4503.111	1	2	012		
4545.220	5	4	007	4545.28 E	4543.5 C
4579.527	5	4	007	4579.49 E	4579.5 C
4590.081	5	5	009		4586.9 C
4609.742	6	7	005	4609.69 E	4608.0 C
4637.351	2	2	050		
4658.079	4	3	005	4658.01 E	4656.5 C
4727.027	4	4	008	4726.96 E	4726.6 C
4736.065	5	4	012	4736.03 E	4734.5 C
4765.028	3	5	013	4764.99 E	4763.0 C
4806.173	6	6	007	4806.10 E	4805.0 C
4847.963	3	6	012	4847.95 E	4847.5 C
4880.004	4	6	009		4879 C
4933.406	1	2	009		4938 C
4965.239	2	4	015		4965.5
5009.426	2	3	060		5007 C
5017.331	1	2	030		5012 C
5062.189	2	3	012		5065 C
5141.909	1	1			5140 C
5145.565	2	2	060		
6114.1	3				6120 C
6140.9	1				
6172.3	3				6173 C
6215.6	1				
6243.7	2				6232 ?C
6482.8	1				
6638.6	2				6628 ?C
6644.2	3				
6684.2	3				

The estimated intensities, according to the three observers, differ very considerably. My own estimates agree better with those of Crookes than with those of Eder and Valenta. I do not, however, attach much importance to this fact; such estimates are always very uncertain; they are influenced by the character of the apparatus and by the kind of plate which is used, and it is very likely that the intensities vary with the pressure and current strength. Since neither Crookes nor Eder and Valenta have obtained the two spectra completely separated, their conditions were different from mine, and in many cases the intensities which they observed may actually have been different from my own.

I have done a great deal of work in searching for series of related lines. Although, on account of the very large number of lines, such an inquiry was by no means promising, its value would have been great if at least some indications had been found as to whether we have to deal with a single element, and if so, as to the place in the natural scale to which it belongs. Unfortunately my labors in this direction have been unsuccessful. No pairs or triplets whatever are found in the blue spectrum, although in the red spectrum I have found three triplets, as follows:

λ	$\frac{1}{\lambda}$	Difference
4702.504	2126527	
4628.623	2160470	33943
4596.205	2175708	15238
4363.970	2291491	
4300.249	2325447	33956
4272.304	2340657	15210
4251.329	2352206	
4190.842	2386156	33950
4164.309	2401359	15203

Here, as we should expect from the triplets observed in other elements, the vibration difference between the first and second lines is about twice as great as that between the second and third; but the intensities do not vary regularly, so that I can attach no importance to these three triplets. The chemical nature of argon is therefore not revealed by spectrum analysis. I desire, nevertheless, to emphasize the fact that I have observed nothing which can lead to the conclusion that argon is a mixture of several elements.

Bonn, April 1896.

A NEW POINT OF VIEW FOR REGARDING SOLAR PHENOMENA, AND A NEW EXPLANATION OF THE APPEARANCES ON THE SURFACE OF THE SUN.

By J. Fényi.

It is known to all that the nature of the central body of our system is still shrouded in the greatest obscurity, and this, the nearest fixed star, offers many problems but few solutions. The phenomena lie clearly before us, but the attempted explanations of their significance are full of contradictions. The latest theories convey to us an impression of the despair which seeks to escape difficulties by every possible path. Such a difficulty is encountered in the enormous atmosphere of the Sun, which may be implied from the height to which the prominences rise, and which in the course of a solar eclipse may actually be seen. In opposition to such evidence as this, calculation shows that a large heavenly body, other things being equal, should have a shallow atmosphere, and that a height which approximates to the radius of the Sun would produce an enormous pressure on its surface, contradicted by observations of the lines of the spectrum. The spectroscope reveals enormous disturbances in this mighty atmosphere, rejected by many observers as incredible. But a sound investigation must not leave the secure basis of observation. Motions on a vast scale appear in such overwhelming evidence that up to the present no observer of the Sun has been found who has been willing to join with the recent theorists. In what follows attention is directed to a new point of view which heretofore has entirely escaped notice, and from which solar phenomena take on a natural and simple aspect, freed from the obstruction of the most obstinate of the contradictions that have been referred to above.

Solar theories are apt to be regarded with the greatest mistrust It is not my intention to add a new one to their number, but merely to give due stress to certain conclusions which follow from the application of established physical laws to the facts of observation.

The following investigations postulate only two assumptions: the first is that enormous velocities, which observations of prominences reveal, are in fact movements of matter. It is an axiom of sound logic that what is seen must be accepted as real until it is shown that a delusion exists which requires a different interpretation of the phenomenon. The second assumption is that the phenomena displayed by the prominences take place in free space. The following investigation is intended to prove that this assumption also is justifiable. The greatest difficulties will thus be removed without creating new ones.

Let us consider the case of a globe of hydrogen whose temperature is 10000°, suddenly transported into free space (by free space is only meant such space as that in which the planets move). Let the radius of this globe be 5800^{km}; its volume will be about that of the Earth, and at the distance of the Sun its apparent diameter will be 16′, and it will present the appearance of a small prominence cloud to an observer. The globe will naturally tend to expand with explosive force; the velocity, however, with which the first layer tends to move off is nevertheless limited, being equal to the theoretical velocity with which the assumed gas diffuses in free space. Computation makes it 9250^{km} per sec. It is obvious that this speed cannot be compared with the velocity of the protuberances. It is, however, evident that this motion cannot spread instantaneously throughout the entire globe; a certain time will be required for the process of expansion to reach the center. The velocity with which the expansion spreads cannot be greater than the velocity with which a difference of pressure in the assumed gas would be transmitted. Here again the purely theoretical formula is to be applied, omitting the coefficient which expresses the relation of the specific heat with constant pressure to that with constant volume; we thus obtain the velocity of 6581^{m} per second.

From this, however, the important result is obtained that it will take fully $14^m\ 41^s$ for the process of expansion to reach the center. This time may be briefly designated in what follows as the interval of expansion. Accordingly, 7^m after the hypothetical globe is transported into free space there will be within it a globe whose radius is only one-half that of the assumed globe, which has not yet been reached by the expansion, and which will therefore shine with unchanged brightness.

This interval of 7^m is in itself more than sufficient to explain the visibility of eruptive prominences. As an illustration I may here cite the prominence which I observed September 30, 1895, and fully described in THE ASTROPHYSICAL JOURNAL for March 1896, p. 192. The small clouds which reached the highest positions were found according to careful measurements to be 472″ high at $10^h\ 23^m\ 44^s.0$; 6^m later, that is to say at $10^h\ 29^m\ 23^s.0$, they had attained a height of 688″ and then disappeared. If these clouds, which were about the size of our globe, had also been at a temperature of 10000°, they might have entered free space at an altitude of 472″ and would still have remained visible at least 6^m, or until they had reached the height of 688″. Similar cases were observed on other occasions.

The observed phenomena of eruptive prominences can be explained without difficulty, if we assume that masses of hydrogen are ejected beyond the atmosphere of the Sun into free space. The great velocity of the prominence does not allow time enough for the complete expansion of the hydrogen while rising; in fact the expansion does not even reach the interior. In the case of such an enormous mass the molecular forces, even at such high temperatures, have only a secondary importance. The gases are to be regarded as compact masses comparable, say, to drops of rain, which may indeed evaporate on their outer surface, but do not disappear. We are therefore by no means compelled to attribute the same height to the atmosphere of the Sun which the prominences occasionally reach.

It is true that the atmosphere has been assumed to be very rare,—in fact inconceivably so; but its great height has always been accepted. As one proceeds outward without limit, a state of rarification is reached which is practically the same as a total absence of an atmosphere; an atmosphere the presence of which cannot be recognized in any way, is a superfluous hypothesis. According to different calculations the atmosphere of the Sun must certainly extend to a great height, although not necessarily above the photosphere. We may assume its bottom to be far below the latter. If, however, it is preferred to hold fast to the idea of an exceedingly rare atmosphere extending to a considerable height above the photosphere, then it is shown in the preceding paragraph that it is by no means necessary to attribute to the prominences existing in it an inconceivable tenuity, which, in consideration of their rapid ascent, is moreover quite impossible. In fact we may attribute to the prominences in free space any density we choose; the process of dispersion will nevertheless have the same rapidity, the duration of visibility of the phenomenon will be the same, for the velocity with which the expansion spreads is independent of the density of the gas. The expansion interval varies directly with the diameter of the mass and is inversely proportional to the square root of the absolute temperature. If we assume a diameter of 64″ for the hypothetical gaseous sphere, it will merely represent an ordinary prominence; but it will be fully an hour before the expansion reaches the center. On the other hand a temperature of 40000° would reduce the expansion interval one-half; higher temperatures are therefore attended by more rapid dissolution, but not by a longer duration of visibility of a prominence.

A very striking characteristic of eruptive prominences is thus explained. I have, for instance, always noticed that the faster a prominence ascends the more rapidly it is dissolved. We are therefore justified in attributing a higher temperature to eruptive prominences, both because they come from a greater depth, and because, on account of their more rapid rising, they must reach the surface with a higher temperature than those of the ordinary type. Their higher temperature is also shown by their unusual brightness. A higher temperature thus explains the more rapid dissolution, whereas, on the assumption that the prominences are cooled by adiabatic expansion in an atmosphere, a longer duration of visibility would be expected.

The explanation of the phenomena here given finds an excellent confirmation in the way in which a detached floating prominence tends to disintegrate. During the ten years of my observations I have witnessed and carefully observed any number of such occurrences. The dissolution does not take place by the enlargement and consequent fading of the prominence, as would necessarily be the case if the elastic expansion extended throughout the mass; but the prominence disappears from without inwards, just as our own clouds dissolve. Even if the brightness does thereby pale, this fact is explained by the decrease of the luminous area with the decreasing diameter. With our conception of these phenomena, we are in a position to assign the temperature of a free floating prominence. It is only necessary to follow the process of dissolution with the proper measurements in order to determine the velocity with which the expansion of the gases travels toward the interior; for this is, according to the following formula, dependent on the temperature only. We have:

$$V=\sqrt{\frac{pT}{d\,273}}$$

in which p is the pressure, d the density of the gases expressed in suitable units, T the absolute temperature, and V the velocity with which the process of dissolution proceeds. We thus obtain a value which, it is true, is somewhat uncertain, inasmuch as other circumstances may modify the visibility, but from which we are nevertheless enabled to arrive at some conclusion respecting the temperature of the Sun; for since the prominence has not time to expand, it cannot cool; it must therefore reach its elevated position with the same temperature it had when it left the surface.

It is noteworthy that the temperature of 10000° adopted above gave an expansion interval which agreed quite well with observation. The extent of the prominence fragments was not measured, but merely estimated from memory; but even if we assume the temperature to have been nearer 20000°, the result must be regarded as a valuable one, when we consider that estimates of the temperature are really nothing better than assumptions, and that they vary from 3000° to 5000000°.

The influence of an elastic expansion is not intended to be denied, or excluded from this discussion. In reality the prominences are not transferred into free space in an instant, but must rise from the lower strata to the higher where the pressure is less, and must therefore assume a corresponding state of expansion, which, after they enter free space, will retard the disappearance of the phenomena by a simultaneous increase of volume.

Let us now return to our globe, which we left in a state of explosive expansion, in order to investigate whether the further expansion will raise any difficulties. The outermost layer will be dissipated into free space with a velocity of 9250^m per second in the direction of the radius of the globe. The heat corresponding to this kinetic energy can be derived from the displaced layer only, since the explosion has as yet left the interior undisturbed. Since no external work is done by this expansion, we can determine the heat by the energy equation according to which the sum of the potential and kinetic energy of every body, which neither receives nor loses energy, is a constant. If we call the mass of the stratum m, the velocity of the molecules at 10000° v, the molecular velocity remaining after the first instant of expansion W, the velocity with which the molecules are dissipated in free space V, we obtain the equation:

$$\frac{mv^2}{2} = \frac{mV^2}{2} + \frac{mW^2}{2}.$$

The temperature which the gases moving off into free space must assume at the first instant is given by W. It is:

$$W = \sqrt{\frac{T}{273}} \times 1848,$$

where 1848 is the velocity in meters of the hydrogen molecules at 0° C., and T the absolute temperature of the stratum. Substituting abc the values applicable to this case, $v = 11335^{m}$, $V = 9250^{m}$, we obtain the temperature 3158° to which the stratum must suddenly fall in the first instant. But even this cannot be maintained for an appreciable interval; the outflowing gas must continue to expand until the entire kinetic energy of the molecules is converted into molar motion. The temperature will then approach absolute zero, the pressure will likewise approach zero, and the molecules thus dissipated will move off in free space with a velocity of 11335^{m}. This complete conversion into energy of molar motion takes place quite rapidly; Hirn[1] showed experimentally that it is accomplished even in the exit tube of a gasometer.

This dispersive process involves one after another of the strata, as the expansion advances inward. The outer strata do not interfere with the inner, since at any instant each outer stratum must have acquired a greater velocity than the next stratum within.

Although an absolutely free space has here been assumed, the essential features of the phenomenon have nevertheless been established with certainty, for obviously the circumstances cannot be materially affected by the assumption of any admissible density in interplanetary space, and a temperature of perhaps —150° C.

If we wish to form some judgment as to the condition of a prominence rising within the atmosphere, we must above all take into consideration the enormous difference of pressure on the Sun. In order to obtain a minimum value of this, than which a smaller value would be absolutely inadmissible, we will suppose that the same temperature exists throughout the whole atmosphere. The differences of pressure at different altitudes are then given by the following formula:

$$p = p' e^{\frac{Gh}{RT}}$$

in which p' and p are the pressures at the upper and lower levels, G is the ratio of gravitation on the Sun to that on the Earth, R

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[1] *La cinetique moderne et le dynamisme de l'avenir*, p. 55.

the known constant of hydrogen, T the absolute temperature and h the height in meters. Substituting in the above the values $R = 422$, $T = 10000°$, $G = 28$; and imposing the condition that $p = 2\,p$, we obtain the result, that in an ascent of only 104^{km} the pressure will be decreased one-half. This result is applicable as long as the law of Gay-Lussac holds true. From it may be drawn the following important conclusions:

I. The pressure in the upper part of the chromosphere, or at an altitude of about 6′, must be 10^{12} times less than that at its base.

II. The pressure at the apex of a prominence whose diameter is 16′, or which is about the size of our assumed globe, must be 10^{23} times less than that at the base. Similar conditions of pressure must exist within the prominence itself, since the law also obtains at the depth where the prominence originated.

III. In consideration of the rapidity of ascent it is to be regarded as an established fact that no prominence can have a lower pressure at its center than that of any stratum previously occupied during its expansion. Let us again apply this to our globe of 16′ diameter and 10000° temperature, to which we will allow the exceedingly small ascending velocity of 10^{km} per second. In accordance with an expansion interval of $14^{\text{m}}\ 41^{\text{s}}$ the globe must still have a central density corresponding to at least that of the solar atmosphere at a depth greater by 8810^{km}. This pressure must therefore be 10^{24} times as great as that of the surrounding atmosphere.

The last deduction unquestionably leads to the conclusion that such a prominence must be in a state of dissolution, just as if it were in free space. A smaller velocity than 10^{km} cannot in general be assumed in such a discussion of the observations, inasmuch as in free space the upper layer itself is dispersed with a velocity of 6^{km}. No ascending motion would therefore exist that could be detected by the observer, or the prominence would not be seen at all.

The view here set forth that the ordinary prominences are also in a state of continual dissolution, is so far supported by observation that prominences of inferior height are seen to be constantly undergoing changes of structure while remaining in the same place. Their existence seems to be one of constant dissolution and renewal. This view naturally explains the usual and characteristic structure of most prominences; they present the appearance of a bundle of luminous pillars or vertical bands and threads, which are drawn out at their upper ends into the finest possible points. In the bands of light we see the streams of gas shooting upward; in the fine points their last remaining traces, vanishing as a result of the expansion,—and we see the same phenomena repeated in the grass-like points of the chromosphere.

EXPLANATION OF THE WHITE PROMINENCES AND THE CORONA.

The phenomena here investigated of expansion in free space above the Sun furnish a natural explanation of the phenomenon of the white prominences, which are only seen during total eclipses, surrounding the red prominences with an ill-defined envelope of silvery light. They are composed of the expanding gas of prominences, which, condensing into a mist, reflects the light of the Sun. This phenomenon follows as a necessary consequence upon the process of expansion of the risen prominence. The temperature of gas expanding in free space must approach absolute zero, until the tension of the gas becomes 0; after which the cloud-like mass moves with the constant velocity of the rising prominence, increased by the velocity of the molecules, out into planetary space. The density of this fog, taking it in the more general sense of the ratio of the mass to the space in which it is contained, is by no means 0. It is easily computed.

For this purpose we will consider the outside layer only, since the interior layers must pass through the same process. Using the same notation as before, the velocity of propagation of the expansion is given by the formula

$$V = \sqrt{\frac{pT}{d\,273}}.$$

If s be the thickness of the layer, we obtain for the time t in which the expansion is propagated through it the value

$$t=\frac{s}{V};$$

but during this time the molecules of the outer surface will have been dispersed with a certain velocity, representing the complete conversion of molecular into molar motion. This velocity of the molecules is given by the formula

$$V'=\sqrt{3\,\frac{pT}{d\,273}}.$$

In the time t, therefore, the outermost molecules will have passed over the distance tV and the pressure of the layer is then

$$s+tV=s+\frac{s}{V}V'.$$

Substituting in this the radical expression above given

$$s+tV=s\left[1+\sqrt{3}\right].$$

The layer under consideration has therefore become $1+\sqrt{3}$ times thicker; its density consequently is only 0.366 the density of the prominence. As the derivation of this result shows, there exists between the density of the prominence and that of the cloudy mass resulting from its dispersion the constant ratio of 0.366, which is independent not only of the density and temperature of the gas at any time but also of its nature.

It would seem to be beyond question that if a prominence has sufficient density to be seen by its own light, the matter which it contains, diffused according to this ratio, must also be visible by reflected light. The brightness of the white prominence will accordingly be determined by the density of the parent red prominence, its extent by the temperature, its height principally by the velocity of ascension.

The density thus determined will subsequently be only gradually and slightly reduced, in proportion as the surface of the white prominence is increased by the divergent motions of the expanding gases. The matter endowed with the velocity above determined will be projected in a definite form out into space; then it will come more directly under the influence of gravity, by which its radial velocity will gradually be checked, and by which the hydrogen, heated once more in the meantime by the solar radiation, will be drawn back upon the body of the Sun.

Since we have recognized the process of gaseous dispersion as active, not only in the lower prominences, but also in the points of the chromosphere, it follows that diffuse hydrogen must cause the Sun to be surrounded on all sides by a brilliant white envelope.

The views which we have held hitherto, with regard to the atmosphere of the Sun, must be considerably modified as a result of this explanation. If by the atmosphere of a heavenly body we mean the envelope of gas resting upon it, the solar atmosphere could hardly be regarded as extending more than a short distance above the chromosphere, which appears by direct observation to constitute such an envelope. Above it is found only dispersed hydrogen (with similar gases), which in its scattered condition gives a continuous spectrum, but which, when heated by the Sun, may easily and, in fact, must show the hydrogen lines; but this matter in no case constitutes an atmosphere, even though certain masses should assume a gaseous state, since these masses do not rest upon the body of the Sun, but gravitate toward the Sun, like cosmical bodies in free space. We may therefore appropriately call them gaseous meteors, which surround the Sun in every variety of form and circumstance of motion like an atmosphere. They constitute the corona.

Powerful eruptions, which are so strikingly distinguished from the ordinary prominences by the enormous scale of their motions, must of course furnish streams which pass far beyond the lower corona, and which are seen in the most capricious forms, especially in times of great solar activity. Their enormous length offers no difficulty, since eruptive prominences frequently give evidence of velocities which exceed even the potential of the Sun. Thus the prominence of September 30, 1895, above cited, had still a velocity of 448^{km} at the height of 11′, whereas the potential at this height is able to generate a velocity of only 409^{km}. This eruption must have produced a stream which extended indefinitely out into space in a straight line. Such streams have been observed during eclipses of the Sun.

This explanation of the corona finds a significant confirmation in the results which J. M. Schaeberle, Astronomer of Lick Observatory, reached in his comprehensive investigations of the outer forms of the corona. He found that all the coronal streamers which were shown in the photographs of the total eclipse of the Sun on April 16, 1893, at Mina Bronces, Chili, coincided with elliptical or parabolic curves having the Sun in one focus; in fact he was enabled to trace the separate streamers back to their centers of eruption, which could actually be recognized on the surface of the Sun. He believes it has been established by his investigations that the coronal streams are nothing else than streams of material ejected from the Sun and illuminated by its light. It is especially noteworthy (as he himself points out) that there is no indication in the form of these streamers of the resisting effect of a medium ; this is an admission which is all the more valuable from our point of view, since he himself seeks to explain the phenomena on the supposition of an extensive solar atmosphere. I thus regard it as confirmed by observation that these phenomena of a supposed solar atmosphere actually take place in free space. When we consider that our meteors, which certainly are compact masses, become luminous even at an altitude of over 100 miles, and that their velocity has been completely checked even at an altitude of many miles, we must recognize the impossibility of the supposition that the exceedingly tenuous matter of the corona passes undisturbed with such an enormous velocity along a path in an atmosphere of any description. The coronal streams require at least the same vacuous space as the comets, which have to pass through the same medium.

It is true that for some time the white prominences have been regarded by Tacchini as nebulous forms of dust-like constitution, and a similar view with respect to the corona has been held, but by the investigation which forms the basis of this paper the origin of this dust-like matter is shown, and the assumption of free space instead of the previous one of an extensive solar atmosphere provides a free path for the outgoing coronal streamers.

The supposition that we see in the coronal streamers hydrogen diffused in the form of dust particles, finds an interesting confirmation in the observations of Schaeberle. He observes that the paths of these streamers at a great altitude are only partly visible, since even the one visible branch appears to extend only to a certain height, its completion above being absent. Our explanation of this fact is, that the hydrogen, or other gas, which is at first solidified by expansion, is heated as it travels along its orbit by the intense rays of the Sun, assumes a gaseous form, and thereupon becomes invisible. Let us consider the circumstances more closely. A path which reaches an altitude equal to that of the solar radius would require sixty-nine minutes for its ascent, the matter would therefore have to exist in dust-like condition, though exposed to the direct solar radiation, for about thirty minutes, if two-thirds of its path is to be seen.

The following table gives the numerical values which are required in order to apply this test to the explanation outlined above:

HEIGHT OF ASCENT (Radius of Sun = 1)	0.1	0.3	0.5	0.7	1.0	2.0
Initial velocity in kilometers per second	184.4	293.7	353.0	392.4	432.4	499.2
Duration of ascent	$12^m\ 53^s$	$25^m\ 43^s$	$37^m\ 33^s$	$49^m\ 33^s$	$69^m\ 0^s$	$3^h\ 8^m\ 19^s$

When we reflect that the ice crystals in our cirrus clouds remain quite unchanged in the Sun's rays, this explanation does not seem to be untenable.

Those streams which have already assumed a gaseous form, afford an explanation of what Janssen termed the photospheric reticulation, which Janssen himself has shown to be due to movements of the solar atmosphere. The currents here discussed afford an explanation which is rendered somewhat more complete by the fact that the great variability of this reticulation within a period of one-half hour agrees closely with the time of descent which is here assumed.

In a precisely similar manner are explained the changes in the streamers of the corona itself; they naturally correspond with the time of ascent of our currents.

Finally, in the gaseous form of the returning currents we have an explanation of the fact that the spectroscope shows the lines of hydrogen, not only in the coronal streamers, but also in the intervals between them.

EXPLANATION OF FACULÆ.

The masses of hydrogen projected from the Sun into space with enormous velocity, being then under the influence of solar gravitation only, must naturally return by a straight or curved path to the surface. They will return to the surface with the same velocity with which they ascended, and must therefore strike the atmosphere like meteors. Even in the highest strata of the atmosphere they will consequently be raised to an enormous temperature, determined by the amount of arrested motion, which far surpasses the temperature of the other parts of the surface; since not only must the enormous heat of the gas lost by expansion be regained, but the enormous kinetic energy of the rapidly rising prominence must be converted into heat, and this is again further augmented by the heat which in the mean time has been gained from the rays of the Sun. That the portions of the surface thus highly heated must shine more brightly than the rest can hardly be called into question. Such brighter portions of the surface are well known as the faculæ. Their nature as revealed by observation agrees quite well with the supposition that they are nothing more than the places where the streams of gaseous meteors which surround the Sun strike its surface. When at a great height the streams will, it is true, spread out to some extent, but in the neighborhood of the surface they will collide with the numerous oppositely directed streams, and will be deflected into paths which may give rise to those irregularly extended forms characteristic of the faculæ. The facts that they do not extend far beyond the Sun-spot zone, and are more numerous in the vicinity of Sun-spot groups may be explained thus: that there the eruptions, of which they are the consequence, have their origin.

I should here like to consider only two characteristic features of the faculæ, the very simple explanation of which, on the basis of the views here set forth, affords an excellent confirmation of the views themselves. As is well known, the faculæ are only visible to the observer when they are near the limb of the Sun. An explanation of this fact has heretofore been sought in the assumption that the faculæ are somewhat elevated portions of the photosphere, which, by the increasing absorption toward the limb lose less of their brillancy than the average surface. If the faculæ are those places where the gaseous meteors strike the Sun's surface, then their more elevated position is explained at the same time, not by the more elevated situation of the photosphere, which in fact cannot be detected by observations of the Sun's limb, but by the heaping up and intense incandescence of gas falling upon the Sun, for the effect here described must be produced even in the highest strata. This explanation is also strikingly confirmed by observation. Secchi wrote many years ago: "Lorsqu'une facule est au bord solaire tout au moins la chromosphère est plus vive et plus haute." I myself observed and remarked on the fact years ago.

This agreement of observations made without predisposition toward any special views is of great significance for the correctness of our theory. A small absorption must be the necessary consequence not only of these conditions, but also of the high temperature of the absorbing strata themselves. Since the faculæ in passing over the limb of the Sun indicate that the greatest height of the chromosphere is inconsiderable, we cannot ascribe a greater height to even the outermost portions of the solar atmosphere than that which the chromosphere attains. In placing the upper limit of the atmosphere at so low a level we also solve the question why the hydrogen above the chromosphere so abruptly ceases to be luminous, for a solar atmosphere in static equilibrium could not possibly be so cold.

We do not wish to conceal from ourselves the fact that the long continuing or quiescent prominences present difficulties on the assumption of an empty space around the Sun, but it should be observed that the difficulty is not removed by the assumption of even a very tenuous high atmosphere, since, as was shown in the preceding investigation, the prominences in such an atmosphere must be in quite the same state of expansion as if they existed in free space. The solution must be sought elsewhere.

A second remarkable peculiarity of the faculæ is, that they show very brightly precisely those lines which are characteristic of the prominences, especially the H and K lines, so that Hale and Deslandres found it possible to photograph the faculæ at the center of the Sun's disk. When this fact was first discovered, M. Deslandres was inclined to regard the faculæ as the projected forms of prominences. This supposition is daily refuted by observation. That the faculæ nevertheless give the same lines is naturally explained by the fact that they are composed of identically the same gases which were elevated by the prominences, and which by again falling on the Sun become incandescent and give rise to the faculæ; the faculæ are identical, not with the rising prominences, but with their component substances falling back into the Sun, and therefore they show the same lines. Thus the glowing gaseous stratum assumed by Hale and Deslandres to exist above the faculæ, merely on the basis of their own observations, receives a confirmation and is quite naturally explained. According to this view no prominences will be found in the position of faculæ; but they may well be found near them, since the returning may give rise to outflowing streams. Hence it is that prominences are often seen by projection over faculæ on the limb of the Sun. This explains why the eruptive activity continues to be displayed for some time over the same group of faculæ.

These currents constantly rising and falling with such enormous velocities are the powerful convection currents which, in the form of prodigious movements, are alone capable of keeping up the enormous quantity of heat continually radiated by the surface of the Sun into outer space.

It only remains to note that my explanation of the faculæ is in the most satisfactory agreement with the theory of Sun-spots recently propounded by Egon von Oppolzer in an address before the Academy of Sciences of Vienna. Herr von Oppolzer's explanation requires a hot layer of gas above the spots. He assumes, not without foundation, that there must be places on the Sun where the atmosphere sinks, and by adiabatic compression acquires a much higher temperature than that of the corresponding level, in quite the same manner as shown by J. Hann with respect to the areas of high atmospheric pressure on the Earth. The explanation here given discloses the dynamic cause of this sinking motion on the Sun, and shows the origin of these highly heated strata; they are found everywhere above the faculæ, and in fact it is in the midst of the faculæ that the spots are known to be formed.

ON THE CAUSE OF THE DISPLACEMENT OF LINES IN THE SPECTRA OF THE PROMINENCES.

The gaseous meteors descending on the Sun afford a surprisingly simple explanation of the most remarkable of solar phenomena; namely, the displacement of the spectral lines. This phenomenon, remarkable alike for its rarity and its exceedingly sudden appearance and rapid disappearance, has hitherto been a prodigy to be wondered at by observers, but not explained. Perplexing in the highest degree has been its appearance at the foot of a prominence in the chromosphere, as well as in the center of the prominence itself at a high altitude. Even if the most tremendous forces are assumed to exist in the interior of the Sun, in order to explain the powerful eruption, it still remained inconceivable how forces could act within a gaseous body in a horizontal direction only, while the least resistance to internal pressure is in an outward direction. Nevertheless, when such a rare phenomenon presents itself, the observer perceives a motion in the line of sight of 100^{km}-200^{km} per second develop along the limb of the Sun, at times over a range of 100000^{km} and in an interval of a quarter of an hour, and continue for many minutes, although a difference of height of only 1000^{km} offers a million times smaller pressure. An explanation of the phenomenon as the result of some kind of explosion is impossible for this reason. But if the assumption is nevertheless made that an explosion would produce enormous and persistent horizontal movements in spite of the inconsiderable upward resistance, then these horizontal movements must take place toward all sides alike, and therefore in opposite directions; displacements toward red and violet must therefore occur simultaneously. This is however by no means the case; on the contrary, motion in only a single direction is usually observed.

This enigmatical appearance is easily and completely explained by the streams of gaseous meteors falling back upon the surface of the Sun. If such a stream should happen to fall upon a region of eruption, the two streams, both of which, according to observation, would generally have some inclination to the vertical, would unite to form resultant currents flowing in a generally horizontal direction.

The differences in direction, intensity and extent of the streams give the means of explaining the strangest peculiarities of these capricious phenomena. Above all, the possibility and usual occurrence of motion in one direction is completely explained, as well as the local character of such disturbances, and the rapid fluctuations of intensity at neighboring points, or even at the same point, so strikingly shown by the flame-like displacement forms which project from the spectral lines, and which indicate enormous velocities never directly observed in the ascent of the prominence. It is not impossible that the union of several favorably directed streams may give rise to a resultant current, the velocity along the axis of which may exceed that of any of the component streams.

Still more remarkable and as little explicable have always appeared to be the displacements of lines in the prominence itself, especially when they are localized at an enormous height. It sometimes happens that a motion of 100^{km}-200^{km} per second may be seen to arise in the course of a few minutes; the motion is confined to one small spot, the surrounding regions being quite unaffected. Occasionally the motion continues but a few minutes; at other times it may last more than half an hour. While it is highly problematical, on the one hand, that such enormous forces can suddenly spring into action at a height of many thousands of miles in the atmosphere, and that the motion to which they give rise can subside in the course of a few minutes, it is not less incomprehensible how such a motion can continue to be visible for the space of half an hour, for in this interval the moving masses would traverse a distance of 300000^{km}.

All these phenomena are easily and naturally explained with the aid of our streams of gaseous meteors. Thus, if a rapidly ascending prominence collides with a descending stream, a lateral component will be produced at the place of the collision, even at the greatest heights, which, if it happens to be directed in the line of sight, must give rise to a corresponding displacement of the spectral lines. Should the ascending masses cease to rise in the direction of the descending stream, the phenomenon would quickly come to an end—the matter diverted from its original course would be dispersed.

It is in this way only that the enormous motions can be explained, that I observed in the prominence of August 18, 1890. On that occasion a motion of 150^{km} per second was developed at a single place $40''$-$50''$ above the Sun's limb, and persisted for half an hour; at the same time a small cloud form or fragment at a height of $370''$ was receding from us with a velocity of 167^{km}, while the apparently adjacent fragments were not in the least affected.[1]

That this explanation assumes the collision of a powerful eruptive stream with an equally powerful descending stream—an occurrence which in itself would seem to be very improbable—only strengthens the views that we have adopted; for we are concerned with the explanation of a very unusual phenomenon, which evidently does not arise from causes that are in daily operation. The collision of such streams is however not so improbable as it might appear, since eruptions are not infrequent in the Sun-spot regions, and the ejected material must generally return to the same part of the surface.

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[1] *C. R.*, 111, 562.

HAYNALD OBSERVATORY,
Kalocsa, January 6, 1896.

FURTHER CONSIDERATIONS IN REGARD TO LAWS OF RADIATION.

By FRANK W. VERY.

A LARGE part of the earlier work on infra-red radiation having been done with apparatus constructed of rock-salt, and having been interpreted at first by the imperfectly known laws of refraction of this substance, it becomes necessary to review and amend some of the earlier conclusions. The recent determinations of the relation between dispersion and wave-length for rock-salt given by Rubens and confirmed by Paschen, being checked by measurements made with fluorite prisms, which are susceptible of greater accuracy than the deviations measured with rock-salt prisms, we must consider these latest results final, and conclude that the dispersion-curve for rock-salt is quite appreciably concave to the axis of wave-length for wave-lengths greater than 3^{μ}. I shall therefore adopt Rubens' constants, given on page 76 of THE ASTROPHYSICAL JOURNAL for January 1896, and Ketteler's formula (3) on page 72, noting that λ in the last term should have the exponent 2, and shall use these values as the basis of further transformations from dispersion to wave-length scale.

I will recall that for reasons given in his paper "Sur les spectres invisibles,"[1] Briot's formula was rejected by Langley, who adopted (for interpolation only) a hyperbolic rock-salt dispersion curve[2] which gave wave-lengths slightly longer than the longest observed by him in the spectrum of a rock-salt prism near $\lambda\, 5^{\mu}$, but otherwise agreed fairly with observation. Approximate wave-lengths greater than 5^{μ} were estimated by a tangent drawn to the curve.

The energy-curve for the normal spectrum of the carbon of an electric arc[3] was deduced by Langley and myself by a slightly different dispersion-curve, founded on the same values, but giving greater weight to the observations near 5^μ, which, even in these earliest measures of wave-length, raise the suspicion of a reversal of curvature. Langley's determinations of wave-length in the rock-salt spectrum ended at λ $5^\mu.3$, too near the point of inflection (at about $2^\mu.8$) to make the existence of the reversal certain. Some variation in dispersive power exists with different specimens of rock-salt in the region between 1^μ and 2^μ, as will be shown further on, but the adoption of Rubens' dispersion-curve will only diminish the wave-length of the normal maximum for the arc-carbon spectrum by about $0^\mu.06$. In the extreme infra-red, however, the changes in the estimated wave-lengths are large. The uncertainty of measurements made with rock-salt prisms is enhanced by the peculiar properties of the substance. Its softness and liability to crack from sudden changes of temperature makes the working of accurate surfaces a task requiring both skill and watchfulness; and its hygroscopic property renders the preservation of these surfaces difficult. Different specimens of the substance probably vary in their dispersion, especially in that extreme infra-red region where, if at all, the absorbent properties of rock-salt for the longer waves are exerted; possibly also in the extreme ultra-violet; and certainly, though to a relatively limited extent, in the region where the dispersion-curve has its sharpest bend. The mode of formation of the substance by evaporation of sea water in seas or salt lakes without outlet, does not favor complete definiteness of composition; and a small amount of impurity, even if uniformly distributed, may affect the dispersive power to a measurable extent. I have, in fact, noticed appreciable variations in the deviation of light transmitted by successive small areas of the principal section of a rock-salt prism, otherwise uncommonly good. The mode of detecting these diversities is to set the cross-wires of the observing telescope upon a sharply defined Fraunhofer line, inserting, between the collimating lens and the prism, a movable diaphragm with

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[1] *Ann. Chim. et Phys.*, (6), 9, 497, December 1886.

[2] Fig. 6, *loc. cit.*, and p. 503.

[3] *Am. J. Sci.*, (3), 40, Plate 5, Fig. 2, August 1890. The curve there attributed to the

"electric arc," is, however, more accurately described as that of the spectrum of the incandescent carbon of the positive pole of the electric arc.

aperture about 0.001 that of the prism, the aperture being moved to and fro across the prism face until all parts are tested. The existence of locally distributed impurities, affecting the refractive power, is immediately indicated by a visible shifting of the Fraunhofer line as the diaphragm changes place. In very bad prisms this defect becomes so prominent that the spectral lines are hazy and almost invisible, until the offending parts of the prism have been cut out by a suitable templet. A variation of deviation, which is systematically connected with the distance of the transmitted pencil of rays from the refracting edge of the prism, is liable to be due to cylindrical prismatic surfaces, but this defect can be tested in other ways. Comparison of deviations in the spectra of two prisms made of material from different localities, namely, one of Baden rock-salt,[1] and the other a "Hastings'" rock-salt prism,[2] shows that the difference of deviation may progressively increase between K and Ω, from 0 to $+2'$.

Probably the most potent influence producing discrepancies in measures made with rock-salt prisms, is the very large variation of refraction with change of temperature. The feeble absorptive and radiative power of rock-salt causes it to change temperature slowly. It is therefore inadmissible to assume the temperature of a rock-salt prism from that of its enclosing walls or surrounding atmosphere, which may differ by many degrees if the temperature is changing rapidly. It is a good plan to take the temperature of a test-piece of rock-salt, similar to the prism and similarly placed, inserting the bulb of a thermometer in a cylindrical cavity drilled to the center of the test-piece, the bulb of the thermometer being surrounded by mercury, and its stem isolated and made tight by cotton wool. Reductions of observations made without this precaution are liable to be quite discordant, unless the temperature of the apparatus remains unusually constant. Comparisons of minimum deviations throughout the visible spectrum of two rock-salt prisms, with a range of temperature of over 30°C. between winter and summer, have shown a change of $-9'.5$ and $-9'.3$ respectively in the minimum deviation of a 60° prism for an increase of temperature of 1°C. within the given limits.

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[1] S. P. LANGLEY, "The Solar and the Lunar Spectrum," *Mem. Nat. Acad. Sci.*, 4, Appendix 2, Washington, 1887.

[2] S. P. LANGLEY, *Ann. Chim. et Phys.*, (6), 9, 1886.

In view of these difficulties to which all measures made with rock-salt prisms are subject, and from the further analogy which, by Ketteler's hypothesis, leads us to expect that a substance so nearly transparent to infra-red radiations as rock-salt will have a dispersion in that region varying at a very moderate rate, I had been somewhat doubtful in regard to the magnitude of the curvature of the extreme infra-red branch of the dispersion-curve, and while employing the smaller wave-lengths indicated by Paschen,[1] had assumed a dispersion-curve so nearly rectilinear in the vicinity of $\lambda = 7^{\mu}$, that the maximum of a spectral energy-curve for $+40°$ C. is scarcely changed by transformation to the wave-length scale. To this Dr. Paschen objects, and I willingly concede the point to him, remarking, however, that the adoption of Rubens' latest dispersion-curve will not materially affect the considerations which were advanced in my note of last November.

With these preliminary remarks I proceed to present anew some old observations, with the changes required to meet the recent advances in our knowledge of rock-salt dispersion, indicating the necessity of a further correction for atmospheric absorption which is not yet sufficiently appreciated, but which cannot be neglected if observations within the range of influence by the great water-band are to be used. New facts are also adduced which emphasize the variety to be expected in the radiative process.

From the prismatic spectral energy-curves published by Langley,[2] I have deduced normal curves for six temperatures by the aid of Rubens' dispersion curve. The transformation-factor in the first column of the following table is such as to give approximate equality of length between $0^{\mu}.4$ and $9^{\mu}.6$, when the areas of the energy-curves are equal on the normal and prismatic scales. For the n and λ curve for rock-salt we have:

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[1] *Wied. Ann.*, 53, 337, 1894.

[2] *Ann. Chim. et Phys.*, (6) 9, Fig. 4, 1886; and *Mem. Nat. Acad. Sci.*, 4, Part 2, Plates 5 and 10, Washington, 1887.

$$n^2 = a^2 + M_2(\lambda^2 - \lambda_2^2)^{-1} - k\lambda^2;$$

differentiating, we get:

$$\frac{dn}{d\lambda} = -\frac{\lambda}{n}\left\{\frac{M_2}{(\lambda^2 - \lambda_2^2)^2} + k\right\}.$$

If the relation between minimum deviation (D) and wave-length (λ) is desired, we must substitute for a 60° prism

$$n = 2\sin\left(\frac{D}{2} + 30^\circ\right),$$

whence

$$\frac{dD}{d\lambda} = -\frac{\lambda}{2\sin\left(\frac{D}{2} + 30^\circ\right)\cos\left(\frac{D}{2} + 30^\circ\right)}\left\{\frac{M_2}{(\lambda^2 - \lambda_2^2)^2} + k\right\} = \tan\phi.$$

The transformation-factor adopted here is $\tan\phi \times 86.5$.

The value of the normal maximum for the temperature +40° C. is $7^{\mu}.54$, a little larger than the number ($7^{\mu}.3$) given in my former note. The maximum is in this case far enough away from the great water-vapor band to be unaffected by its presence, especially since the air at the time of the measurements was very cold and dry; but owing to the smallness of the excess, the maximum would be considerably displaced if a comparison-screen at absolute zero were to be substituted for the actual screen at — 6° C. I estimate that such a substitution would increase the wave-length of the apparent maximum about $0^{\mu}.5$, which would make the corrected value $\lambda_{\max.} = 8^{\mu}.04$. The positions of the normal maxima for the hotter bodies would not be appreciably changed by the adoption of an absolutely cold comparison-screen; but a glance at the values of the normal maxima will show the necessity of a further correction for the influence of the great water-vapor absorption band between 5^{μ} and 7^{μ}. The maximum for 815° C. is too far from the great band to be affected; but at temperatures above 300° C. and below 800° C., the normal maximum being of shorter wave-length than the band, the wave-length of the apparent maximum is too small, while it is too large at temperatures below 200° C., because the band is here on the opposite side of the maximum. Assuming that the normal maxima for the extreme temperatures have not been altered by this cause, I adopt such a curve as will distribute the errors between these points, obtaining thus the final corrected $\lambda_{max.}$, and the product $\lambda_{max.} \times T$ indicated by Paschen's law, as well as $\lambda_{max.} \times \sqrt{T}$ required by Michelson's law.

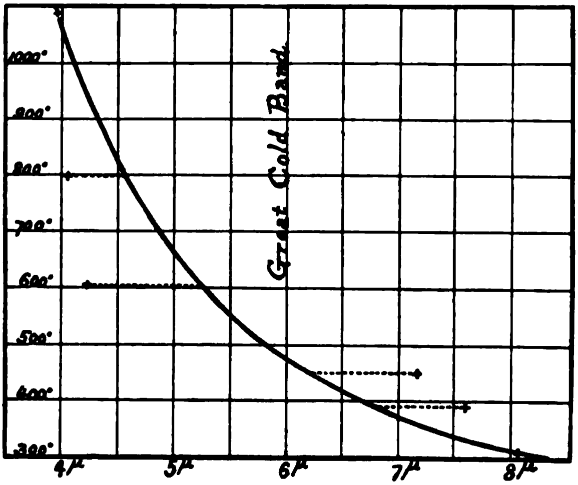
The oxidized copper in the following measures had been thickly coated with lampblack, but the lampblack had probably mostly burned off at the highest temperature, except perhaps where protected in the surface pores.

SPECTRAL ENERGY-CURVES.

Reduction by Rubens' dispersion-curve			815° C., 1088° Abs.		525° C. 798° Abs.		330° C. 603° Abs.		178° C. 451° Abs.		119° C. 392° Abs.		40° C. 313° Abs.	
Transformation Factor	Rock-salt Min. Deviation	Wave-length	Prismatic ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate	Prismatic Ordinate	Normal Ordinate
0.398	39°30′	1μ.93	960	382	620	247	350	139	...	...	...	...	....	....
0.302	39 20	2 .67	3220	972	1440	435	960	290	263	79	...	...	....	....
0.323	39 10	3 .53	5800	1873	3510	1134	1760	569	312	101	...	...	....	....
0.366	39 00	4 .28	5230	1914	3310	1211	1900	705	375	137	145	53	....	....
0.410	38 50	4 .93	4450	1825	2780	1140	1580	648	413	169	165	68	....	....
0.452	38 40	5 .50	3750	1695	2310	1044	1260	570	426	193	178	80	....	....
0.493	38 30	6 .03	3090	1523	1880	927	1000	493	424	209	185	91	31	15.3
0.531	38 20	6 .52	2550	1354	1540	818	770	409	415	220	184	98	34.5	18.3
0.567	38 10	6 .99	2060	1168	1270	720	610	346	399	226	179	102	37.5	21.3
0.600	38 00	7 .42	1680	1008	1040	624	460	276	375	225	172	103	38	22.8
0.632	37 50	7 .83	....	....	....	....	....	...	344	217	163	103	35.5	22.4
0.663	37 40	8 .22	....	....	....	....	....	...	316	210	152	101	32	21.2
0.692	37 30	8 .59	....	....	....	....	....	...	290	201	141	98	29	20.0

Absolute Temperature T	Prismatic Maximum	Normal Maximum	Corrected $\lambda_{max.}$	$\lambda_{max.} \times T$	$\lambda_{max.} \times \sqrt{T}$
1088°	39°10′	3μ.96	3μ.96	4308	130.6
798	39 06	4 .05	4 .55	3631	128.5
603	39 02	4 .24	5 .24	3160	128.7
451	38 37	7 .16	6 .20	2796	131.7
392	38 27	7 .60	6 .80	2666	134.6
313	38 02	[8 .04]	8 .04	2517	142.2

In the reduction of these measures which Rubens has given,[1] the spectral energy-curves have not been redrawn on the normal scale. As corrected here for water-vapor absorption, it will be seen from the last two columns of the previous table that the wave-lengths of the normal maximum ordinates follow Michelson's law more closely than Paschen's. The products ($\lambda_{max.} \times T$) are by no means constant. Paschen's law is therefore only applicable to the body (iron oxide) from which it was obtained.



Curve showing probable position of maximum in a normal spectral energy-curve, if undisplaced by the absorption of the great water-vapor band. Radiating surface = lampblack. Abscissas = $\lambda_{max.}$ Ordinates = absolute temperature.

An extension of the lampblack curve to the position of the normal maximum for the electric arc carbon gives a value of ($\lambda_{max.} \times T$) twice as great as that observed, indicating that lampblack approaches the ideal absolutely black body more closely than graphite. It is evident that no reliable estimate of the solar temperature can be obtained from these curves without a knowledge of the selective radiating power of the solar photosphere.

Differences in selective radiating power may be so great as to entirely alter the form of an energy-curve, as is well shown in

[1] *Wied. Ann.* 53, 267, 1894.

the following comparison of the spectral energy-curves of an Argand and a Welsbach burner, the total radiation being approximately equal:

Wave-length	$0^{\mu}.50$	$0^{\mu}.60$	$0^{\mu}.72$	$0^{\mu}.98$	$1^{\mu}.44$	$1^{\mu}.93$	$4^{\mu}.28$	$7^{\mu}.42$	$9^{\mu}.60$
$\left.\frac{\text{Welsbach}}{\text{Argand}}\right\}$ Ratio	2.000	0.971	0.530	0.566	0.735	0.791	1.042	1.909	1.777

Here the maximum energy has the greater wave-length in the Welsbach curve (rock-salt prismatic maximum of Welsbach $=39° \; 15'$, of Argand $=39° \; 28'$), although the incandescent mantle cannot differ greatly from the temperature of the radiating carbon particles of the Argand flame. With the same consumption of gas, the Welsbach burner radiates much more powerfully than the Argand burner,[1] and loses a smaller proportion of its heat by convection, owing to the impeding of the hot gaseous circulation by the friction of the fine meshes of the mantle. The figures given above do not fully express the great superiority of the Welsbach over the Argand burner as an illuminant. With equal flow of gas (3.6 cu. ft. per hour), the static pressure being 3.5 inches of water, and the flow-pressure 2.5 inches, the candle-power of the Welsbach light was 3.18 times that of the Argand, the Welsbach light having nearly 3 times the intensity of the Argand in the orange of the spectrum and 6 times the Argand intensity in the blue as determined by measures with a spectrophotometer. The heat lost by radiation was:

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[1] The open-meshed mantle of the Welsbach burner occupies only a fraction of the flame section, but so also do the scattered particles of incandescent carbon in the Argand flame. Not knowing the relative fractional sections occupied by the incandescent material, we can only say that the process is something like this: We may suppose that the intrinsic radiating power of Welsbach material is somewhat less than that of carbon. Then, if the fractional sections occupied by the Welsbach mesh and by the swarm of carbon particles are equal, the Welsbach material must be hotter for equal radiation, and still hotter for a radiation thrice as great, while it could only have the same temperature if its fractional section were correspondingly larger. But in view of the partial transparency of luminous flames, it is not probable that the carbon particles occupy more of the section than the Welsbach mesh. We may conclude, then, that the Welsbach mantle is not necessarily hotter than the carbon particles, in spite of the greater extent of its spectrum toward the short wave-lengths; but there can be no doubt that the Welsbach flame, area for area, disperses more energy in the form of radiation than does the Argand. Arguing from the ordinary analogies, the greater extension of the Welsbach spectral energy-curve towards the short wave-lengths would indicate that the Welsbach source is the hotter, but the longer wave-length of its maximum that it is the colder, while the fact that the radiation of both sources is supplied by the consumption of equal amounts of an identical gas would favor a substantial equality of temperatures. Probably the third alternative is correct.

3065 small calories per minute from the Welsbach.
1086 small calories per minute from the Argand.

while a rough estimate of the convection losses gave:

8000 small calories per minute from the Welsbach.
10000 small calories per minute from the Argand.

The above is a striking illustration, but by no means an extreme case, of the difference in the selective radiating power of different substances, and in addition to this we have frequently considerable changes in the selective radiating power of the same substance at different temperatures.

The original measurements in the spectrum of the positive carbon of the electric arc given by Langley,[1] were for comparison with solar measurements made with the same arrangement of apparatus, and for this purpose require no correction for the impurity of the spectrum, since both spectra are affected alike; but in transformation to the normal scale where the true form of the spectral energy-curve is required, a correction for the impurity of the spectrum is necessary, and has been applied in the reduction already cited.[2] From the smooth curve which represents the original measures very closely, the following normal values have been taken:

λ	$0^{\mu}.6$	$0^{\mu}.8$	$1^{\mu}.0$	$1^{\mu}.2$	$1^{\mu}.4$	$1^{\mu}.6$	$1^{\mu}.8$	$2^{\mu}.0$
Energy.....	270	420	500	510	493	440	362	296

The maximum is at $1^{\mu}.16$, or $1^{\mu}.10$ by Rubens' dispersion-curve. It would be forcing the observations unjustifiably to make the position of the maximum less than $1^{\mu}.1$.

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[1] *Am. Jour. Sci.*, (3), 38, 438, December 1889.

[2] *Am. Jour. Sci.*, (3), 40, Plate V., Fig. 2, August 1890.

It is true that the energy-curve for the spectrum of the positive arc-carbon is only a first approximation, and that a very large number of similar curves must be summarized in order to get one ideally accurate; but it does not seem necessary to wait for this. The results already published are not likely to be grossly erroneous. Some irregularity in the arc-carbon radiation must be expected, since the arc is never still for very long at a time. In this kind of observation nothing will take the place of continuous human supervision, and in Langley's work one assistant was detailed to keep the hottest part of the incandescent carbon centered in respect to the spectroscope slit and axis of collimation; but it is evident that when the arc leaps to the opposite edge of the crater, it must take some seconds before this part can become as hot as that previously in view, even if the adjustment of position is made instaneously; and thus irregularities are produced in the spectral energy-curve which are fortuitous, and which have to be removed by drawing a smoothing curve. While, however, there must be variations of temperature produced by arc-fluctuation, the explanation of electric arc-phenomena recently given by Professor S. P. Thompson in his Cantor lecture before the London Society of Arts,[1] which supposes that the solid carbon is covered by a thin layer of melted carbon continually vaporizing, or even in a state of active ebullition in the case of a hissing arc, suggests that on the whole the variations of intrinsic radiating power cannot be excessive, if the surface in the vicinity of the issuing arc is kept near the constant temperature of a liquid boiling point.

Dr. Paschen, from his hypothesis in regard to the wavelength of maximum radiation,[2] computes the temperature of the positive carbon in the arc at 2729° Abs., but direct observation must take precedence. Wilson and Gray, cited in my previous note, found the temperature of the positive carbon 3600° Abs. or 3300° C. Their method founded on the use of Joly's expansion thermoscope, is perhaps open to criticism; but the latest result of Violle, 3600° C. or 3900° Abs., is so thoroughly guarded, and made moreover by one whose skill as an experimenter is of the highest order, that it deserves exceptional weight.

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[1] Reported in London *Industries and Iron*, November 1, 1895, and in later numbers of *The Electrician*.

[2] ASTROPHYSICAL JOURNAL, 3, 153, February 1896.

In 1892 Violle,[1] working with an arc produced under very varied conditions, the consumption of power varying from 500 to 34000 watts, found that the intrinsic brilliancy of the positive crater is identically the same for arcs of these different powers. This had also been observed by Rosetti and by Abney, though for a much smaller range. This constancy suggests as a cause one or the other of the two chief means by which uniform temperature can be maintained in the midst of surrounding thermal change. Either the carbon is at its melting point or its boiling point, unless possibly these two points coincide, carbon having no intermediate liquid state. If Professor Thompson's suggestion is accepted, we may suppose the liquid layer to exist, but to be so thin that it escapes detection except through the bumping of its explosive boiling. The fact, however it is to be explained, assures us that the temperature of the electric arc carbon does not vary through more than a very slight range. Having settled this point, Violle proceeded to determine the temperature of the incandescent carbon by knocking off fragments of the hot tip into a calorimeter, protected by asbestos screens, and corrected by blank experiments executed before and after the measurement. The result would therefore be a minimum (there being a slight loss of heat in the fall of the piece) were it not that it was necessary to use a theoretical value of the specific heat of carbon in the reduction which gave the temperature of the positive carbon 3500° C. This defect Violle subsequently remedied,[2] finding that:

"1. Above 1000° the mean specific heat of graphite increases linearly with the temperature according to the formula $C_0^t=0.355+0.00006\,t$.

"2. The heat given up by 1 gram of solid graphite between its temperature of volatilization and 0° is 2050 calories.

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[1] *C. R.*, 115, 1273, 1892.

[2] *C. R.*, 120, 868, 1895.

"3. Consequently the temperature of ebullition of carbon is 3600°."

The experiments of Dr. Louis Duncan[1] show that the electromotive force, necessary to vaporize carbon, increases with the atmospheric pressure. At 1 atmosphere the fall of potential at the positive pole is 39 volts, as Professor S. P. Thompson had previously shown, but at 10 atmospheres the fall is 48 volts. The boiling point of carbon therefore probably rises with the pressure, and at such pressures as Jewell finds at the solar photosphere, the temperature of condensation of carbon mist must be very much higher than 3600° C.[2]

In another article by Violle[3] it is shown that while the temperatures of the carbons remain constant, they being cooled by evaporation, the arc itself is, in general, hotter than the carbons and grows hotter with increase of current. But I pass this by, as we are here dealing with the spectra of solid bodies. It seems to me, however, that ample evidence has been adduced, proving that the temperature of the positive electric arc-carbon cannot be less than 3900° Abs. for which $\lambda_{\max.} \times T = 1.10 \times 3900 = 4290$, and that Paschen's law of radiation completely breaks down at high temperatures, while it can only be allowed as an approximation at low temperatures for a particular substance which does not fulfil the ideal of an absolutely black body so well as lampblack, for which a different law is indicated. Owing to causes some of which have been described in this article, in the present state of infra-red measurement, discrepancies in the value of supposed "constants" which would be intolerable in more exact branches of physics, are less of a reproach than it is to be hoped they may eventually become.

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[1] London *Electrician*, 31, 360, 1893.

[2] The experiments of W. E. Wilson (*Ap. J.*, 2, 212, October 1895) at first sight appear to prove the opposite of this, but are really inconclusive. It is probable that the electric power was insufficient to maintain the arc at high pressures, for it is hardly possible that the presence of an atmosphere of nitrogen should totally change the physical properties of the arc. A crucial test would be to find whether the temperature of the positive carbon (kept always at the maximum temperature obtainable with unlimited electric power) does or does not rise with increasing pressure.

[3] *C. R.*, 119, 949, 1894.

THE SPECTROSCOPE OF THE EMERSON McMILLIN OBSERVATORY.

By H. C. LORD.

DURING the winter of 1895, Mr. Emerson McMillin wrote to the Board of Trustees of the Ohio State University offering to build and equip an observatory. Plans for a building were at at once prepared by Professor Bradford, and a site chosen, well to the northwest of Columbus, which is almost entirely free in clear weather from the smoke of the city. A committee was appointed to select the apparatus and, as a member of the committee, the writer was sent East to visit several observatories and instrument-makers. In equipping this institution, two considerations were to be met: first, an opportunity should be offered to the students of the state for thorough elementary as well as advanced instruction in Astronomy; second, it should be prepared to take up at least one line of astronomical investigation and carry it out successfully. In consideration of the above facts, it was deemed wise to purchase a combined transit and zenith telescope, chronograph, chronometers, sextants, etc., for instruction, but to devote the bulk of our money to an equatorial of as large aperture as possible, provided with a powerful spectroscope having a wide range of dispersion. The equatorial is of 12½ inches clear aperture with objective by Brashear and mounting by Warner and Swasey. This mounting is too well known to need description. It is simple, elegant, massive in design, and accurate in workmanship. No attempt has been made to cumber it with the so-called conveniences sometimes applied to modern telescopes, but everything that is necessary is on the instrument and in exactly the place that it should be. The objective is of the new form made by Mr. Brashear, and has given most excellent satisfaction.

The spectroscope is shown attached to the telescope in Plates II. and III. A brass ring bolted to the tube holds, by means of a bayonet joint, a heavy hollow cylinder of brass. The lower end of this carries a position circle graduated to degrees. Over this cylinder fits a jacket, which can be turned through 360° about the axis of collimation and clamped in any position. In this are fastened two thin steel tubes, about 46^{mm} in diameter, carrying the spectroscope proper. The general design of this instrument is a sort of combination of the star spectroscope of the Lick and Potsdam observatories. A light but very rigid framework, built up of sheet brass, and clamped by four split hinged rings to the rods from the jacket, carries the collimator. This can be moved along the axis of the telescope by a rack and pinion, clamped, and its position read on a scale graduated to millimeters. To the lower end of this framework is attached a counterbalanced arm to carry the observing telescope or camera. This arm is also built of sheet brass and is hinged at two points, as is done on the Lick spectroscope. The angle of deviation is given by a circle 200^{mm} in diameter reading to thirty seconds of arc. The prism table is similar to that of the Lick spectroscope, except that it is on the same side of the instrument as the graduated circle, and carries an arm ending in a vernier also reading to thirty seconds of arc. Behind the slit-plate is a diagonal eyepiece for viewing the star from behind the slit. The jaws open symmetrically, the amount being measured by a graduated head reading to the $\frac{1}{500}$ of an inch. The comparison apparatus and cylindrical lens (which is attached to the spectroscope as arranged for the grating for the sake of illustration) are well shown in the figure. The instrument thus far described is arranged to carry either a grating, 60° dense prism or a 60° light prism.

At my request Mr. Brashear designed and built the attachment shown in Plate III. This consists of a brass box, provided with two dense 60° prisms automatically kept at the angle of minimum deviation, into which either the observing telescope or the camera can be screwed. Two brace rods run from these tubes to the body of the spectroscope, clamping them rigidly in place. A diagonal eyepiece is used to observe the image of the star and slit from the front face of the first prism, as is done at Potsdam. The instrument is provided with a double set of objectives, one for the visual and one for the photographic portion of the spectrum. Diaphragms are provided whereby the ratio of focal length to aperture can be kept the same as in the great objective of the equatorial. As to the ease with which this instrument can be attached to the telescope, it is sufficient to say that one man can remove the micrometer and replace it by the spectroscope in less than sixteen minutes, while the change from the battery of two prisms to the single prism can be made in five minutes.

I give below a few of the dimensions of the instrument:

Clear aperture of objectives - - - -	44^{mm}
Focal length of objectives about - - -	380^{mm}
Ruled portion of grating is - - - -	$35^{mm} \times 46^{mm}$
No. lines to inch of grating - - - -	14438
The dense prism is - - -	$60^{mm} \times 40^{mm}$ on its face
The light prism is - -	$70^{mm} \times 50^{mm}$ on its face
The prisms of the battery are -	$56^{mm} \times 38^{mm}$ on their faces.

Linear dispersion on photographic plate from F to midway between H and K when G is in minimum deviation is as follows:

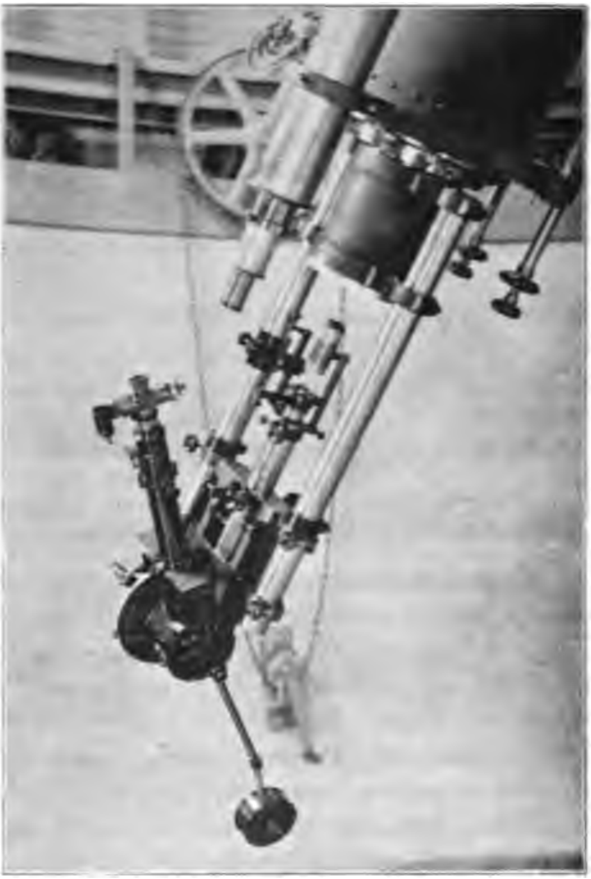
For light prism - - - -	$13^{mm}.1$
For dense prism - - - - -	$21^{mm}.3$
For battery of two prisms - -	$43^{mm}.1$

The following scales are provided, all graduated in the same way and all reading to millimeters, except that for slit-width: for focus of collimator, observing telescope, camera, cylindrical lens, position of slit with respect to the great telescope, and the circle which gives the position of the observing telescope and prism.

Of the optical qualities of this instrument it is needless to speak; the definition is simply superb and the mechanical construction leaves almost nothing to be desired.

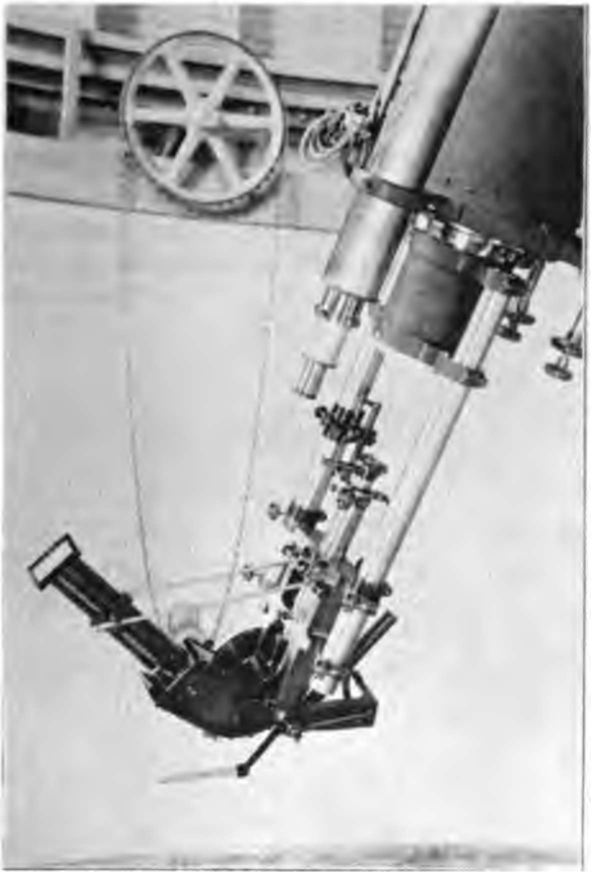
In connection with the spectroscope, the observatory possesses an excellent comparator by Carl Zeiss. This is provided with two micrometer microscopes reading to thousandths of a milli-

PLATE II.



THE SPECTROSCOPE OF THE EMERSON McMILLIN OBSERVATORY.

PLATE III.



THE SPECTROSCOPE OF THE EMERSON McMILLIN OBSERVATORY.

meter. One has a rack and pinion movement for focussing on the photographic plates; the other is fixed over a scale 100^{mm} long, graduated to fifths of a millimeter. The divisions are the finest I have ever seen; their errors have not yet been investigated, but the work will be begun at an early date.

The building is shown in the Frontispiece. It is built of gray pressed brick, rock-faced in the second story, and contains an office, library, class room, clock room, dome, dark room, transit house, hall way, two closets and a large basement.

The entire carpenter work was made by our college carpenter, Mr. Woodruff, and the patterns for the dome mechanism by the students of the university. Thus far everything has given entire satisfaction.

THE MODERN SPECTROSCOPE. XIX.

THE OBJECTIVE SPECTROSCOPE.

By GEORGE E. HALE and F. L. O. WADSWORTH.

LIKE most forms of spectroscopic apparatus in use at the present time, the objective prism is due to Fraunhofer. In his first attempts to observe the spectra of stars he employed a prism of 60° angle, supported in front of a theodolite objective of 3^{cm} aperture. Subsequently he used a prism of 37° 40′ angle with a comet-seeker of 10^{cm} aperture, a cylindrical lens being held before the eye for the purpose of broadening the spectra. With this apparatus Fraunhofer observed the characteristic features of the principal types of stellar spectra, and measured with a micrometer the positions of the more important lines.[1]

In 1838 Lamont repeated these observations with the original apparatus of Fraunhofer, but without adding anything to the earlier results. Secchi observed the spectrum of Sirius with a theodolite and objective prism in 1855, but his extensive investigations of stellar spectra were not commenced until 1862, when he employed for his earlier observations a direct-vision pocket spectroscope attached to the Merz refractor of the Collegio Romano. Having exhausted the capabilities of these and other direct-vision spectroscopes, and desiring to push his investigations still further, he applied a prism $16^{cm}.2$ in diameter, of 12° refracting angle, to the nine-inch refractor of the observatory. With this apparatus the D and *b* lines in the spectrum of Aldebaran were separated by a distance of 315″, and the D lines and many groups of iron lines between *b* and E were resolved. The spectrum of α Lyrae required two minutes to transit across a fixed cross-hair, and Secchi suggested that the relative positions of the lines could be determined by noting their time of transit. That part of the objective which was outside the circular prism was covered except in two places. At one of these points a circular hole was left, so that a star could be observed directly; at the other was placed an achromatic prism giving a deviation of the image equal to that of the objective prism, so that a colorless image of a star could be observed at the same time with its spectrum.[1] This device did not give satisfactory results, and it was replaced by Fraunhofer's arrangement of a finder fixed with its axis inclined to the axis of the equatorial at an angle equal to the deviation of the prism. Both of these arrangements were used not only for the purpose of setting the equatorial upon the star, but also to give points of reference in measuring the positions of the spectral lines.[2]

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[1] *Denkschriften d. K. Akad. d. W. München*, 5, 1817.

Respighi early adopted the objective prism for his investigations of stellar spectra, and in 1871 both he and Lockyer used objective spectroscopes for observing the spectrum of the corona during the total eclipse. Prismatic cameras have also been used with success at the eclipses of 1882, 1886 and 1892. In 1885 Professor Edward C. Pickering adopted the objective prism for the extensive researches on stellar spectra established in that year at the Harvard College Observatory in memory of Dr. Henry Draper. Photography was used for the first time in recording stellar spectra with an objective prism, and the results far surpassed those of the earlier visual observations. In the course of this work prisms of small angle (from 5° to 13°) and of 8, 12 and 24 inches aperture, have been employed in photographing most of the stars within their reach in the northern and southern skies.[3] During the last few years Professor J. Norman Lockyer has used an objective prism of 6 inches aperture and 45° refracting angle in his photographic studies of stellar spectra at South Kensington. At Herèny, Hungary, Herr Eugen von Gothard has made excellent photographs of the spectra of the stars and planetary nebulæ with an objective prism of ten inches aperture, attached to a reflecting telescope.[4]

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[1] SECCHI, *Le Stelle*, p. 80.

[2] *Ibid.*, p. 84.

[3] *A. and A.*, 11, 199, 1892.

[4] *A. and A.*, 12, 51, 1893.

THEORY OF THE OBJECTIVE SPECTROSCOPE.

As has already been pointed out in previous papers, the three questions which most concern us in considering any form of spectroscope are the resolving power, the brightness of the spectrum, and the practical visual and photographic purity of the spectrum. As a basis of comparison we will assume, as in the general discussion of the astronomical spectroscope, a constant resolving power *r*. For the objective spectroscope it is only necessary to consider the case of stellar spectra, and these may be divided into two classes: bright line spectra, and continuous spectra.

As regards brightness, it is generally admitted that the objective spectroscope has a great advantage over every other form of instrument of the same resolving power. This advantage is due to two distinct causes: (1) the greater simplicity of this form of instrument and the correspondingly less loss of light by reflection and absorption.[1] (2) The concentration of all the light from the source (save the loss by reflection and absorption just noted) in the spectral image.

In the case of the compound spectroscope, only a part of the light from the star image can pass through the slit, even when the optical definition and achromatism is perfect (as is never the case with refractors) on account of the finite width of the diffraction pattern. If the achromatism were perfect, the image steady and the slit width just equal to the diameter of the second dark ring, about nine-tenths of the total light from the star image would be transmitted.[2] In general, on account of the diminution of purity with increase in slit width, we cannot admit of a slit width more than one-half as great as this, or about equal to the diameter of the *first* dark ring; and under these conditions over

[1] If the resolving power is constant the loss by absorption in the prism train (if a prism train is used) will be the same for all forms of instrument which employ simple prisms; but there will be an increased absorption in the compound spectroscope by reason of the two additional lenses. The loss by reflection in the compound spectroscope will be much greater, not only on account of the larger number of optical surfaces involved, but also on account of the larger angle of the prisms employed. There will also be considerable loss by reflection from the edges of the slit, etc.

[2] *Phil. Mag.*, March 1881.

16 per cent. of the light is lost, or more than is lost by reflection from the faces of a single 60° prism.

In the case of the refractor there is a further loss for all but one particular region of the spectrum, by reason of the want of achromatism and the consequent enlargement of the diffraction image for those wave-lengths which are out of focus. There is also an important loss in the intensity of the spectral image of bright line spectra, due to the further broadening of the slit image by the diffraction of the observing telescope.

Taking into account all of these losses, and supposing the slit width equal to the diameter of the first diffraction ring, as above, we obtain for the intensity of the spectral image in the case of the compound spectroscope[1]

$$i \cong \frac{1}{3} k e \frac{\beta^2 A^2}{r \lambda (\lambda_1 - \lambda_2)} \quad \text{for continuous spectra;} \qquad (1)$$

and $$i = \frac{1}{4} k e \frac{\beta^2 A^2}{\lambda(2\lambda + \frac{1}{4} r \Delta \lambda)}{}^{*} \quad \text{for bright line spectra;} \qquad (2)$$

where k is a constant whose value depends on the apparent intensity of the star, *i. e.*, on its absolute intensity k_0 and its angular magnitude ω, or,

$$k = k_0 \omega^2 .$$

These formulæ are deduced on the assumption that the slit width is equal to the theoretical diameter of the first diffraction ring, but that the star image is uniformly bright across the whole width of the slit, which will be the case when the tremor disk due to aberration is about twice the theoretical diameter of the central diffraction image. If we assume theoretically perfect conditions, which will be convenient in comparing the brightness of the spectra formed by the objective spectroscope with those obtained by a compound spectroscope under the very

[1] See *Ap. J.* 1, 52, 1895.

[*] In deducing this formula in a previous paper, the assumption was made that the effective broadening due to diffraction and dispersion was one-half the total broadening. Since then it has been found that the factor is more nearly one-third than one-half. The only change which this introduces in the expression for i is in the coefficient of $r \Delta \lambda$, which becomes one-quarter instead of one-third as given in previous papers.

best conditions, the coefficients in the above formula will be slightly changed. For we have, using the same notation as above: For the equivalent effective width of slit in case of compound spectroscope $\cong \frac{1}{2} s \cong \frac{\lambda}{\psi}$; and for the average intensity of star image $k_0 \omega^2 \frac{A^2}{(\omega A + \lambda)^2} \psi^2 \cong k \frac{A^2}{\lambda^2} \psi^2$;

$$\therefore i = \frac{2}{3} k \epsilon \beta^2 A^2 \frac{1}{r\lambda(\lambda_1 - \lambda_2)} \text{ for continuous spectra;} \qquad (3)$$

and $i = \frac{4}{5} k \epsilon \beta^2 A^2 \frac{1}{\lambda(2\lambda + \frac{2}{5} r \Delta\lambda)}$ for bright line spectra.[1] (4)

In the corresponding case of the objective spectroscope we evidently have for the intensity of the spectral image of a star

$$i' = k_0 \gamma^2 \frac{S^2}{\left(\frac{\omega A + \lambda}{\beta}\right)\left[\frac{\omega A + \frac{1}{3}(2\lambda + r\Delta\lambda)}{\beta}\right]} \qquad (5)$$

where γ is the angular magnitude of the telescope objective as viewed from the star, and S the linear magnitude of the star.

Hence $i' = k \epsilon' A^2 \beta^2 \frac{1}{r\lambda(\lambda_1 - \lambda_2)}$ for continuous spectra, (6)

and $i' = m k \epsilon' A^2 \beta^2 \frac{1}{\lambda(2\lambda + r\Delta\lambda)}$ for bright line spectra. (7)

In the last formula, the constant m varies from $m = 2$ for small values of $r\Delta\lambda$—for which the effective broadening in the direction of the length of the spectrum is nearly one-half the total broadening—to $m = 3$ for large values for which the effective broadening is more nearly one-third the total. As a mean value m may be taken to be two and one-half.

In case the diffraction image is broadened by aberration due to atmospheric irregularities, etc., the intensity of the spectrum is diminished. For continuous spectra this diminution is simply proportional to the increased broadening of the spectrum (since the length of the spectrum is only inappreciably increased). Hence for the case assumed for (1) (in which the broadening by aberration is about equal to that caused by diffraction), the inten

[1] See preceding footnote.

sity of spectrum for the objective spectroscope would be diminished by about one-third

or
$$i' \cong \frac{1}{2} k \epsilon' A^2 \beta^2 \frac{1}{r\lambda(\lambda_1 - \lambda_2)}. \qquad (8)$$

For bright line spectra the intensity would be diminished more, since both the width and height of the line are increased. To find the effect we must add to both terms in the denominator of (5) a term of the form

$$\frac{\kappa}{\beta} = \frac{\kappa}{A} F \;*$$

where κ is a constant depending upon the amount of aberration, *i. e.*, on the disturbances in the atmosphere.

We then obtain for i

$$i = k \epsilon' A^2 \beta^2 \frac{1}{[\omega A + \frac{1}{2}(2\lambda + \kappa)][\omega A + \frac{1}{2}(2\lambda + r\Delta\lambda + \kappa)]}. \qquad (9)$$

If we assume as before that the term κ is equal to 2λ, *i. e.*, that the total broadening is twice that due to diffraction alone, and neglect ωA as very small in comparison with the other terms, we get

$$i' \cong \frac{3}{4} k \epsilon' A^2 \beta^2 \frac{1}{\lambda\left(2\lambda + \frac{r\Delta\lambda}{2}\right)} \qquad (10)$$

In all of these cases i, (and i'), is to be regarded as the intensity near the center (of the width) of the spectrum, and the range $\lambda_1 - \lambda_2$, in the case of continuous spectra, must be no larger than is consistent with approximate uniformity of the spectral intensity between these limits.

Comparing $\left\{\begin{matrix}(3) \text{ and } (6)\\ (1) \text{ and } (8)\end{matrix}\right\}$ and $\left\{\begin{matrix}(4) \text{ and } (7)\\ (2) \text{ and } (10)\end{matrix}\right\}$ we see that under the conditions which are most favorable to the compound spectroscope the intensity of the spectrum produced by the latter is not more than two-thirds in the case of continuous spectra,

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*The longitudinal aberration is proportional to $\frac{\kappa}{\beta^2}$ (Rayleigh, *Phil. Mag.*, Nov. 1879), and the resulting broadening of the image is therefore proportional to $\frac{\kappa}{\beta^2}\beta$, or $\frac{\kappa}{\beta}$, as above.

and less than one-third in the case of bright-line spectra, of the intensity of a spectrum produced by an objective spectroscope of the same resolving power and angular aperture.

Under practical conditions the advantage of the latter instrument is even more marked, because ϵ is always less than ϵ', generally not more than three-fourths to one-half as large. In general, therefore, we may say that for a moderate[1] theoretical resolving power and given telescope, the intensity of the spectrum formed by the objective spectroscope is about twice as great in the case of continuous spectra and from four to five times as great in the case of bright line spectra, as with the compound spectroscope having an observing telescope of the same angular aperture as that of the main telescope.

This gain in intensity, although important in itself, is greatly accentuated by a corresponding gain in the purity of the spectrum. This is a point which, strangely enough, seems to have been overlooked. It is easy to show that the objective spectroscope is in fact the only form in which the purity of the spectrum, under the most favorable conditions, may be equal to the full theoretical resolving power of the spectroscope train. For we have for the expression for purity

$$P = \frac{\lambda}{s\psi + \lambda \dfrac{\lambda\left(\dfrac{r}{R}\right)}{2s\psi + \lambda\left(\dfrac{r}{R}\right)} \lambda\left(\dfrac{r}{R}\right)} r \tag{11}$$

where r is the theoretical resolving power of the instrument as ordinarily defined, and R the theoretical resolution for lines of width $\Delta\lambda$. But in the case of the objective spectroscope

$$s\psi = \omega A.$$

For stars the term ωA may be neglected in comparison with λ. (It can hardly be more than $\frac{1}{10}\lambda$ even in the case of the largest telescope now in use.)

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[1] For very large resolving powers the advantage is less marked in bright line spectra because of the greater importance (*i. e.*, larger coefficient) of the term $r\Delta\lambda$ in the case of the objective spectroscope.

Hence, if there is no appreciable aberration

$$P = R$$

or the purity is equal to the maximum theoretical resolution.

If we assume corresponding conditions in the case of the compound spectroscope, the diffraction pattern at the focal plane of the observing telescope will be

$$I = \int_{-\frac{\sigma}{2}}^{+\frac{\sigma}{2}} \frac{\sin^2 \phi}{\phi^2} \cdot \frac{\sin^2 \frac{\pi}{a_0} (\gamma - \phi)}{\left[\frac{\pi}{a_0} (\gamma - \phi)\right]^2} d\phi = \psi(\gamma, \alpha).$$

If the width of the slit is equal to the diameter of the first diffraction ring of the star image, $\sigma = 2\pi$. Under these conditions the value of I, for the part of the curve with which we are most concerned in determining resolution, is practically the same as that given by the integral

$$\int_{-\infty}^{+\infty} 2^{-\frac{\phi^2}{w^2}} \frac{\sin^2 \frac{\pi}{a_0} (\gamma - \phi)}{\left[\frac{\pi}{a_0} (\gamma - \phi)\right]^2} d\phi = \psi(\gamma, w\alpha),$$

where the effective angular width w of the source is equal to σ. This last integral has already been investigated, and it has been shown that the diffraction curve which it represents is of such a form that resolution of a double source of which the two components were equal would occur when the angular distance between the centers of the geometrical images is

$$\Omega = \frac{4}{7} w + \frac{\alpha^2}{w + \alpha}. \qquad (12)$$

In this case, that of a slit symmetrically illuminated by the central diffraction image of a star,

$$w = \frac{2\lambda}{a}, \text{ and since } \alpha = \frac{\lambda}{a},$$

then

$$p_s = \frac{\lambda}{\frac{8}{7}\lambda + \frac{1}{3}\lambda} r = \frac{2}{3} r,$$

or the maximum purity (for absolutely monochromatic radiations) attainable with the compound spectroscope with the above width of slit is only two-thirds the maximum purity obtainable with the same resolving power in the objective spectroscope. It may be easily proved that the latter has a similar advantage in the case of non-monochromatic radiations.

If, then, we compare the intensities of the spectra produced by the two forms of instrument on the basis of constant *purity*, we see that in the case of continuous spectra the objective spectroscope is not twice but more than three times as efficient as the compound form, since in order to obtain the same purity of spectra with the latter the resolving power must be increased 50 per cent. and the intensity correspondingly decreased, both by the increased linear dispersion and the increased losses by reflection and absorption. With bright line spectra the same increase of resolving power is necessary (for constant purity), but the diminution in the intensity is less, because of the less effect of the increase in the terms containing r.

In case the image is broadened by aberration caused by atmospheric disturbances, the distribution of intensity in the star image will probably not differ greatly from the "law of errors" curve already assumed as representing the distribution in intensity in a spectral line of width $\Delta\lambda$. Hence, if we replace w by $\frac{\kappa}{A}$ in the expression for Ω (12) we get

$$p'_s = \frac{\lambda}{\frac{4}{7}\kappa + \frac{\lambda}{\kappa+\lambda}\lambda} r.$$

For a value of κ such as we have already considered in the calculation of intensities, (8) and (10), *i. e.*, $\kappa = 2\lambda$, we have

$$p'_s = \frac{2}{3} r = p_s.$$

For the corresponding case of the compound spectroscope (actual slit opening same as before) we have

$$p''_s = \frac{\lambda}{2\lambda + \frac{1}{5}\lambda} r = 0.45 r$$

and $$\frac{p''_s}{p'_s} \cong \frac{2}{3} \text{ as before.}$$

If we double the aberration and open the slit of the compound spectroscope until the same quantity of light passes as before, we will practically halve the purity for both forms of instrument. We therefore come to the practical conclusion that the objective spectroscope has the same advantages over the compound form in the way of brightness and purity of spectra under bad conditions as it has under good conditions of work. But it must not be forgotten that with the slit spectroscope we can always attain any given degree of purity (less than the theoretical resolving power) by closing the slit and sacrificing the brightness of the spectrum. In the case of the objective spectroscope, however, the degree of purity attained at any time depends entirely on the value of κ, that is on the conditions of "seeing." For this reason the latter instrument does not possess the same advantages for photographic as it does for visual work. For in visual work there are occasional moments of good definition and of these the eye makes the most. Since the conditions of observation are frequently good enough to permit of nearly the limiting theoretical resolution of the telescope objective being reached in double star work, it would seem that we might hope to attain under these same conditions the full theoretical resolution of the objective spectroscope, and thus resolve and observe lines in stellar spectra (and possibly measure their position), which we can never hope to see with the compound spectroscope (such, for example, as the components of D_3). This advantage does not seem to have been as yet appreciated or at least utilized.

For photographic work the conclusions already drawn hold, provided the angular aperture of the telescope is sufficiently small to enable the full visual resolving power to be photographically attained. In order to do this the focal length must be from thirty-five to forty times the aperture (see THE ASTROPHYSICAL JOURNAL, May 1896, pp. 345–6). For large refracting telescopes it would be almost impossible to attain this ratio, but in reflectors it could be easily done by using the Cassegrainian form It is important to notice that the effect of aberration on the resolving power varies only as the first power of β, and is therefore independent of the focal length. The main difficulty in photographic work is, that since the final record is the result of an integration in time, so to speak, the variation in the size and the mean position of "aberration disk" of the star on bad nights will be very prejudicial to the purity of the photographic record. But the magnificent results obtained by Pickering in photographing the spectra of α Aurigae, α Bootis, α Canis Minoris and many other stars with an objective prism of only eleven inches aperture, show how much we may reasonably hope to achieve with objective spectroscopes of apertures equal to those used in connection with our best compound spectrographs, provided only that efficient prisms or gratings of the necessary size can be constructed. In this case the larger the aperture the better the results likely to be attained spectrographically, because of the shortening of the time of exposure and the greater possibility of utilizing the brief intervals of good definition.

METHODS OF DETERMINING MOTION IN THE LINE OF SIGHT WITH THE OBJECTIVE SPECTROSCOPE.

The principal objects for which the objective spectroscope is likely to be used and for which its advantages over the compound spectroscope would be most manifest, are: (1) Spectrographic surveys for the purpose of determining spectral types of stars and for singling out interesting objects for more detailed examination. (2) Spectroscopic or spectrographic studies of particular lines or groups of lines in the spectra of certain stars, with reference either to their character or their identification. (3) Measurements of velocities in the line of sight. (4) Accurate measurements of absolute wave-lengths for the purpose of determining shifting of the lines by the effect of pressure, etc.

The first of these objects is the only one for which the instrument has been extensively used, and the success which it has achieved in this line of work is too well known to require further comment. The great advantages of the objective spectroscope for observations—particularly visual observations—of the second kind have been pointed out in the preceding paragraph. For the last two purposes, both of which involve accurate measurements of absolute or relative wave-lengths, the instrument has scarcely been used at all, although its application to (3) has frequently been suggested. We give below the various methods of measuring relative and absolute wave-lengths with the objective spectroscope which have been proposed by others, together with certain suggestions and experiments of our own.

TELLURIC LINES.

In Dunér's important researches on the rotation of the Sun, telluric lines were used as the standards of reference, and differential measures of the displacement of certain metallic lines were made at opposite ends of a solar diameter. The high precision of these measures would lead one to suppose that no reference marks better than telluric lines could be found for determinations of stellar motions in the line of sight, whether with the slit spectroscope or the objective prism. The B band and other telluric groups are visible in the spectra of many stars,[1] but in their position at the lower end of the spectrum the stronger lines do not offer very good marks for the micrometer; it is probable, however, that certain telluric lines could be advantageously used for the purposes of visual measurement. Were it not for the insensitiveness of photographic plates to orange and red light, there would be no difficulty in photographing the stronger lines with a good spectrograph, and under the very best conditions some of the finer lines, which could be more accurately measured, might be obtained. With commercial isochromatic plates, water-vapor lines such as those at λ 5886.193, λ 5887.445, λ 5919.860 and especially λ 5901.682 on Rowland's map might perhaps be photographed with the best spectrographs. It must be admitted that under existing conditions it is hardly probable that any of these lines could be photographed with an objective spectroscope, unless it have some such resolving power as the Draper eleven-inch telescope with four objective prisms at the Harvard Observatory. Professor Pickering has searched for telluric lines in his large collection of photographs of stellar spectra, but hitherto without success.[1] It is to be hoped that photographic plates which are sensitive in the lower spectrum will ultimately be obtainable, as they cannot fail to be of great value for work of this kind.

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[1] W. W. Campbell, *Ap. J.*, 2, 163, 1895.

ABSORBING MEDIA IN THE TELESCOPE.

It might be supposed that artificial lines could be produced in the objective spectroscope, by the absorption of media placed in the telescope tube, between the objective and the eye or the photographic plate. The only experiments which to our knowledge have been made in this direction are those of Professor Edward C. Pickering, carried on at the Harvard Observatory.[2] Didymium salts gave lines that were too diffuse, hyponitric fumes were unsatisfactory and of all the substances examined, not one produced lines which were sufficiently well-defined to permit of accurate measurement. While it is doubtful whether absorption spectra thus produced would give satisfactory results, it is perhaps worth while to make further experiments with various absorbing media. Only those could be successfully used which in comparatively small thicknesses give narrow and sharply defined lines, and but little general absorption.

MISCELLANEOUS METHODS.

In *A. N.* 3289 M. Artémie Orbinskij gives a method of measuring stellar motions in the line of sight by the aid of an objective prism. The spectra of two stars are photographed side by side on the same plate, and the displacements $d\lambda_1$ and $d\lambda_2$ of two lines at the extremities of one spectrum with reference to the corresponding lines in the other spectrum are carefully measured. The velocity of one star with respect to the other is then given by

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[1] *Harvard College Observatory Annals*, 26, Part 1, p. xx.

[2] *Ibid.*

$$v = V\frac{d\lambda_1 - d\lambda_2}{n_1\lambda_1 - n_2\lambda_2},$$

where V is the velocity of light, and n_1, n_2 are the number of revolutions of the micrometer corresponding to a tenth-meter for the wave-lengths λ_1, λ_2 respectively. In making the photographs the objective prism is supposed to be in its ordinary position with the refracting edge parallel to the diurnal motion of the stars. It is evident that any relative displacement of the spectra in declination will materially affect the result. As the telescope must be set in different positions in order to bring on to the plate the star to be investigated and a second star of known velocity, difficulties due to flexure, variations in the temperature of the prism, and the gradual change of refraction during the exposures (tending to make the lines cross the spectrum obliquely) would probably be encountered. M. Orbinskij suggests methods of overcoming the first two of these difficulties, and others will be mentioned in the course of this paper.

In a note published in this JOURNAL,[1] Professor E. B. Frost describes a method similar to that of M. Orbinskij, which he devised in 1893. Instead, however, of bringing two stars side by side upon the same plate, Professor Frost proposes to measure the perpendicular distance between corresponding lines in the spectra of a star whose velocity is known and any other star on the plate whose velocity is desired, corrections being applied to reduce the measures to the center of the field. He is not prepared to say that the errors due to the distortion by the lens and prism will be less than those due to flexure in pointing at different stars in M. Orbinskij's method, nor does he consider that the plan proposed could compete with the spectrographic method. The chief value of Professor Frost's suggestion seems to us to be, as he himself points out, the possibility it affords of determining "the direction and order of velocity of a great number of stars, and thus to sift out large velocities and interesting cases" on just such photographs as those in Professor Pickering's extensive collections.

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[1] *Ap. J.*, 2, 235, 1895.

It should be added that the essential principle of the methods of M. Orbinskij and Professor Frost was recognized by Professor Pickering in 1891, as the following words indicate[1]: "The change in length of the spectrum due to the motion of the star would only amount to about one-sixth of the total motion, and could not readily be distinguished from a variation in temperature of the prism."[2] Mr. Maunder has recently stated that the same idea occurred to him in 1875.[3]

In the course of his investigations Professor Pickering made a number of experiments with auxiliary prisms, with the purpose of forming an image of the star itself upon some portion of the spectrum, to serve as a basis of measurement. The dispersion and deviation of the objective prism were neutralized by a small prism, and an achromatic prism having the same deviation as the objective prism was then inserted. As well-defined images could not be obtained in this way on account of the secondary spectrum, trial was made of a doubly reflecting prism like a Fresnel rhomb, consisting of two right-angled prisms placed face to face, one of them having the necessary inclination. The color of the objective prism was not completely corrected however, and the auxiliary prism was then tried near one edge of the objective, the large prism having been moved to give it space. In this position the secondary spectrum of the lens gave a winged image of the star, a difficulty which was not overcome by further experiments.[4] If a hole were cut through the objective prism, and the reflecting prism placed at the center of the objective, it is probable that good results would be obtained. The form of double reflection prism shown in Fig. 1*a*, which has only three optical surfaces, would also be preferable to the Fresnel rhomb, on the score of both compactness and cheapness.

In the February 1896, number of the *Observatory* Mr. Maunder describes certain methods of using the objective prism for measuring stellar motions which occurred to him several years ago. In the first of these a second telescope is attached to the tube of the principal telescope at such an angle as to point directly to the star, the photographic plate being placed at the point of intersection of the two optical axes. The star's trail is thus photographed upon the spectrum, and serves as a reference mark. In the second plan the refractive angle for different parts of the stellar spectrum is measured on the declination circle of the equatorial The third method requires the use of an objective prism smaller in aperture than the objective, so that stars whose positions are known may be photographed on the same plate with the spectra. The value of these methods would. depend upon the possibility of eliminating the effect of flexure in the first two cases, and of correcting for atmospheric refraction in the third.

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[1] "Preparation and Discussion of the Draper Catalogue," *Annals Harvard College Observatory*, **26**, Part I., p. xxi, 1891.

[2] It is perhaps worth mentioning that the differential displacement of the lines might be greatly increased by using the prism out of the position of minimum deviation.

[3] *Obs'y*, 19, 84, 1896.

[4] *Ibid.*

M. Deslandres has recently proposed that by means of a slit and collimator placed in front of the objective prism, a metallic spectrum be photographed on the same plate with that of the star; a second star spectrum and a second metallic spectrum are then photographed on the same plate. The displacement of corresponding lines in the stellar spectra less that of the same lines in the comparison spectra give the relative velocities of the two stars. The function of the comparison spectra is to eliminate errors due to changes in temperature of the prism and flexure in the telescope tube. Since it is essential to accurate measurement that the angle between the star and the axis of the telescope be exactly the same during each exposure, a finder is attached at a fixed angle to the telescope tube, and the observer keeps the star on the cross-hairs by means of the slow motions. Errors in guiding are determined by measurement of the star image photographed at the focus of a third telescope attached to the finder. This is essentially Fraunhofer's original form of apparatus, with the micrometer replaced by a photographic plate, and the addition of a third telescope and an arrangement for producing comparison spectra. It is not easy to see any important advantages of this device for determining stellar motions. As compared with the spectrograph, the gain in shortness of exposure due to the use of the objective prism would probably be offset by the loss in accuracy resulting from the relative flexure of the various parts of the apparatus. Moreover, as Professor Keeler has already pointed out in a review of the method,[1] the resolving power of the instrument as used for the production of comparison spectra would of necessity be very small, even if a prism of large angle were employed. For this reason, the comparison lines would be poorly defined, and consequently not well suited to accurate measurement.

The idea of using a comparison spectrum with the objective prism is not an entirely new one. Several years ago Professor Pickering determined the scale of his objective prism photographs by a process analogous to, but not identical with, the one suggested by M. Deslandres. The 11-inch Draper telescope, with its battery of four objective prisms, was placed in such a position that the parallel rays of sunlight coming from a slit at the focus of a horizontal 15-inch reflecting telescope, entered its objective, and formed a solar spectrum in the center of the photographic plate.[2] The full aperture of the prisms was utilized in this way, but it is evident that serious errors might arise from the difference in temperature of the prisms and the flexure of the telescope. Several methods of using a comparison spectrum also suggested themselves to one of the present writers two years ago, but no description of them was published.

In all of the methods hitherto described a comparison spectrum in which is utilized the full resolving power of the prism, is needed to determine the effect of variations in the temperature of the prism and in the flexure of the telescope. Such a comparison spectrum can be obtained if the objective spectroscope is used as a Littrow spectroscope (Fig. 1). Light from the spark at *E* enters the slit at *S* and falls upon the right-angled prism *P*,[3] from which it is reflected through the objective and the objective prism. If the prism is so inclined that the light of the spark falls normally upon its outer face, some of this light will be reflected back to form the spectrum of the spark upon a photographic plate at the focus of the telescope. The dispersion in this case would be twice that of the stellar spectra formed by the same prism, but this would be an advantage in detecting displacements due to changes of temperature, etc. If, however, it were desired to have the dispersion the same as that of the stellar spectra, the objective prism could be made of two prisms of equal angle separated by a narrow air space, as indicated in the figure. The light from the spark would then be reflected back at the second surface of the lower prism. In this case the compound prism could be used at the position of minimum deviation for the star, while in the first plan proposed the departure of the prism from minimum deviation would increase with its refracting angle. On account of the comparatively small amount of light reflected back from the prism, the exposure on the spark spectrum might be continued during the whole time of the exposure on the star, a very decided advantage. If the light is too feeble, the reflecting surface could be very lightly silvered, but except in the case of the very brightest stars this would probably be unnecessary. We believe that a combination of this method

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[1] *Ap. J.*, 3, 311, 1896.

[2] *Annals Harvard College Observatory*, 26, Part I., p. xvi., 1891.

[3] Placed on one side of the axis of the telescope.

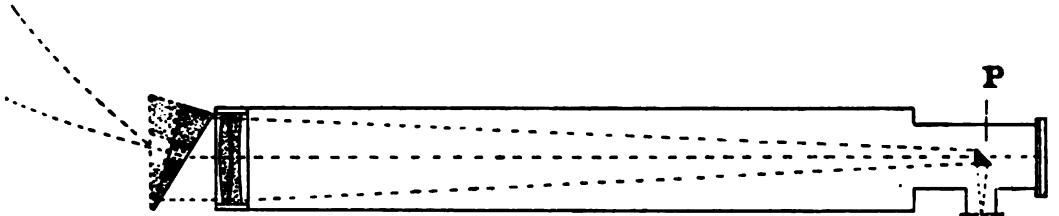

Fig. 1

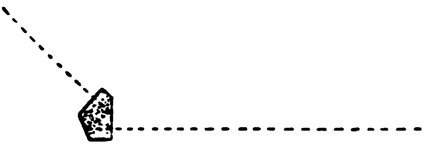

Fig. 1a

for producing comparison spectra with either the double reflection prisms of Fig. 1*a* placed at the center of the objective or with the methods of measurement of Professor Frost or M. Orbinskij, would be likely to yield valuable results.

For the sake of completeness it may be added that Zöllner's reversion prism device might be used with the objective spectroscope for the determination of motion in the line of sight in four ways: (1) After photographing the spectrum of the star and spark (using the comparison method suggested above), the objective prism is rotated through 180°, the telescope again set upon the star, and the process repeated. The perpendicular distance between two lines in the comparison spectra, minus that between the corresponding star lines, gives the displacement required. It is evident that corrections would be needed for errors in pointing the telescope and following the star. (2) In order to reduce the errors due to flexure, a direct-vision objective prism might be used, rendering unnecessary the second pointing of the telescope. So far as we know, the only direct-vision objective prism hitherto employed proved to be unsatisfactory on account of its great absorption.[1] Except for small apertures, the direct-vision prism-mirror combination, first suggested by Fuess and reinvented by one of the present writers,[2] would also be impracticable on account of the size of the optical flat required. (3) After the star and comparison photographs

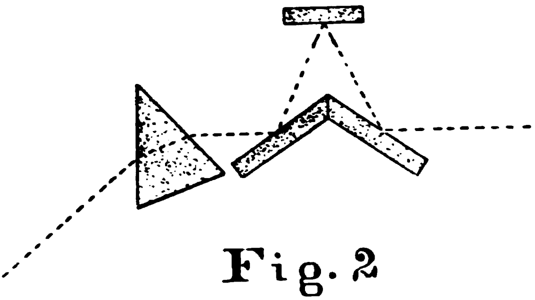

Fig. 2

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[1] KONKOLY, *Handbuch für Spectroskopiker*, p. 258.

[2] *Phil. Mag.*, October 1894.

have been taken as in (1), a reversion attachment formed of three plane surfaces (Fig. 2) is placed between the prism and the objective, and a second set of exposures made. (4) Or this reversion attachment may be made to cover one-half the objective, so that the direct and reversion photographs can be made simultaneously, the reversion device being so constructed that the reversed stellar spectra fall slightly above or below the direct ones, and not upon them. This reversion arrangement, although much cheaper than a large reversion prism, would likewise be impracticable for large apertures for the same reason as in (2).

Another method upon which some experiments have been made, and which will answer well under some conditions for making absolute measurements in prismatic spectra, is an interference one similar in principle to that first employed by Rubens,[1] and more recently by Rubens and Snow,[2] in the measurement of wave-lengths in the infra-red spectrum. In Rubens' apparatus the two parallel glass plates which were used to produce interference bands were placed outside the slit of the spectrometer. In the case of the objective prism this arrangement is obviously impossible, and the two plates must be placed just in front of or just behind the prism. The interference phenomena produced by the double reflection from the two contiguous surfaces of the plates are the same in either case, and consist, as is well known, of a series of dark bands crossing the spectrum at points whose wave-length is determined by the relation

$$\lambda = \frac{2d \cos i}{m} = \frac{K}{m},$$

where d is the perpendicular distance between the two plates, i the angle of incidence of the light, and m a number depending on the order of the interference. The two quantities K and m on the right hand side may be determined by experiment by using the instrument to form a solar spectrum, and measuring the position of two bands of order m and $m+a$ with reference to two Fraunhofer lines of known wave-length, λ_1 and λ_2. These two quantities once determined, the wave-length of a line in any spectrum may be found by comparing its position with that of a band of known order.

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[1] *Wied. Ann.*, 45, 238, 1892.

[2] *Wied. Ann.*, 46, 529, 1892; *A. and A.*, 12, 231, 1893.

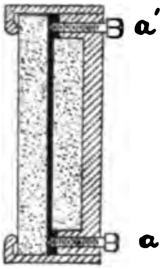

Fig. 3

It is to be observed that in this method of determining absolute wave-lengths a change in the index of refraction of the prism by reason of a change in temperature, or a change in deviation caused by a shifting of its position, is without effect on the result. All that is necessary is that the distance d, and the angle i, shall remain constant.

The first may be best secured by making one plate slightly larger than the other and clamping both in a rigid metal frame of a cross section shown in Fig. 3, the distance between the two plates being adjusted by means of screws a, a'. To secure the maximum quantity of light, the back reflecting surface should be full silvered and the front one "half silvered." These two plates are placed in front of the prism, and make a fixed angle with it and the axis of the telescope, being most conveniently placed so as to give the direct vision combination previously referred to.

In the preliminary experiments with this arrangement no difficulty was experienced in setting on the center of the interference fringe with sufficient accuracy, even though the latter was several times broader than the spectrum lines. Indeed, as is well known, the accuracy of setting on a line or fringe increases until the width becomes at least ten to twenty times the width of the cross-wires. The principal difficulty is that when a line falls near a minimum it is rendered so faint as to be very difficult to set upon. The great practical difficulty is the same as before, *i.e.*, the necessity for using two large optical flats, one of which would require in this case to be a plane parallel piece. With very large apertures the use of such a combination would of course be out of the question.

THE OBJECTIVE GRATING.

The most direct and convenient method of determining both relative and absolute wave-lengths with the objective spectroscope is, as with all others, by the use of a grating in place of a prism train. The use of the objective grating in place of the objective prism was first suggested, we believe, by Jewell,[1] who proposed an ingenious method of making a transmission grating by photography. It was recently pointed out that this plan would be impracticable in the case of large telescopes, because the plate on which the grating is photographed would have to be an optical flat, which would be more expensive than one of the lenses of the objective itself.[2] If this method of making a grating were adopted, it would be better and more practical to either photograph it directly upon the front face of the objective, devoting the telescope exclusively to spectroscopic work for the time being, or to have an extra front lens (which would be somewhat less expensive than an optical flat of the same size and quality), and photograph or *rule* the grating permanently upon it. Another plan suggested[3] by one of the writers was to make an objective grating by Fraunhofer's original method. A trial grating of this kind has since been constructed in our workshop by Mr. William Gaertner for the 12-inch refractor of the Kenwood Observatory. Two screws 27^{cm} long with about 63 threads to the centimeter were carefully cut in brass, on a Rivett precision lathe. For the purpose of making the preliminary experiments described below it was considered sufficient to finish the screws in the lathe, without grinding. They were then cut in two along their axes, and the half screws mounted parallel to each other on the opposite sides of rectangular frames 33^{cm} by $36^{cm}.5$, made of brass bars of $2^{cm}.5$ square section. The two frames were next clamped together and mounted on centers, and No. 40 B. & S. copper wire at constant tension was wound across the screws in the successive threads, as Fraunhofer made his first gratings. After the winding had been completed the wires were soldered to the screws, and the frames separated, leaving two transmission gratings with perfectly opaque lines and transparent spaces. The brass frames were each provided with four clamping-screws, by means of which they could be easily fastened to the cell of the 12-inch photographic objective.

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[1] *A. and A.*, 13, 44, January 1894.

[2] *Ap. J.*, 3, pp. 61–62, 1896.

[3] *Ibid.*

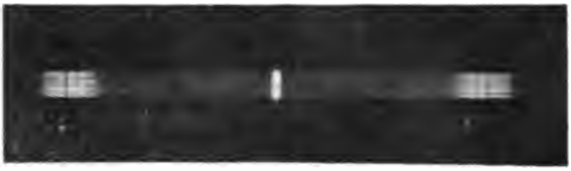

FIG. 4.

Sirius was selected as the first star to be photographed, and early in March several exposures were made on its spectrum with fairly successful results. After the focus had been determined a large number of stellar spectra were photographed during March and April.[1] One of these is reproduced in Fig. 4.[2] In examining this photograph it should be remembered that the grating is a very coarse one, the total number of wires being only about 1700. As the ratio of aperture to focal length in the telescope is $\frac{1}{18}$, it is evident that the photographic resolving power could hardly be greater than about 800, even under theoretically perfect conditions. On many nights the grating wires were set into vibration by the wind, and in most cases the seeing was not very good in the early evening, when the exposures were made. It is therefore not probable that the effective resolving power exceeded 400 to 500, or that of a dense flint prism of about 5^{mm} base.

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[1] Many of these photographs, including those referred to in the text, were made by Mr. S. B. Barrett, Fellow in Astrophysics in The University of Chicago.

[2] In order to bring out the lines clearly, it was necessary to strengthen them somewhat on the glass positive from which the cut was made. The second order spectra are easily obtained with somewhat longer exposure.

The absolute wave-lengths of the lines in stellar spectra photographed with the objective prism are determined from the ordinary equation of the transmission grating

$$\lambda = \frac{s}{m} \sin\left(\frac{\delta_1 + \delta_2}{2}\right),^*$$

where δ_1, δ_2 are the angular distances of corresponding lines from the central image, s the grating interval and m the order of spectrum. The scale of the photographs is easily determined by measuring the linear separation of stars whose positions are known. In a series of measures of the lines $H\gamma$, $H\delta$, $H\epsilon$, and $H\zeta$ in the first order spectra of 54 Leonis we have obtained the wave-lengths 4339.4, 4101.1, 3970.6, 3890.6, Rowland's values (neglecting the last two places of decimals) being 4340.7, 4101.8, 3970.3, 3889.1 respectively. The mean error of measurement in this case was about 1 tenth-meter or about $\frac{1}{12}$ the practical resolving power of the telescope. There should be no difficulty in constructing objective gratings in the manner described with at least twice as many lines to the centimeter, and with apertures as great as a meter. In order to prevent the wires from vibrating in the wind they may be soldered to light rods running across the frame parallel to the screws. With such a grating the accuracy of measurement ought to be increased at least twenty-five times, making it possible to determine velocities in the line of sight with an accuracy approaching that attainable with a slit spectroscope.

The exposure must of course be considerably longer with objective gratings than with objective prisms and they can, there-

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*A slight correction is necessary if the incident light is not perpendicular to the plane of the grating, *i. e.*, if the central star image is not in the optical axis of the telescope or if the grating is not perpendicular to the latter.

fore, hardly be expected to compete with prisms except for certain purposes. The facility with which wave-lengths can be measured in the photographed grating spectra is a strong point in their favor. The cost of the gratings is also comparatively small, the one used in our experiments not exceeding one-thirtieth that of an equally large objective prism of small angle. This last advantage becomes of course more and more marked as the aperture increases. For example, the objective grating which it is proposed to make for the Yerkes telescope should cost less than one-half of 1 per cent. as much as an objective prism of the same resolving power and aperture.

KENWOOD OBSERVATORY,
May 20, 1896.

MINOR CONTRIBUTIONS AND NOTES.

ON MR. JEWELL'S OBSERVATIONS OF THE SPECTRUM OF MARS.

MR. LEWIS E. JEWELL again contends, in the April number of this JOURNAL, that all the spectroscopic observations of Mars thus far made were totally inadequate for detecting water-vapor in that planet's atmosphere. I am disposed to accept his conclusion, but not his reasoning.

The *reason* which Mr. Jewell assigns for his belief is that the resolving-powers of the spectroscopes employed were entirely too low to show the individual vapor "lines." Is his reasoning correct? In my opinion it is wrong. The nature of the observations seems to be unfamiliar. May I quote a paragraph from my paper on "The Spectrum of Mars"?[1] "Now while all these lines can be observed *individually* in the solar spectrum, owing to the high dispersion which can be used, they can only be observed as groups or bands in the Martian and lunar spectra, on account of the faintness of those spectra and the low dispersion which must be employed." On the page of my paper immediately following the above quotation, Mr. Jewell can find eight or ten other passages to the same effect. I did not claim to see the individual "lines" (introduced by our atmosphere), but only the "bands" or "groups" of lines collectively. The question of resolving power has so little to do with the problem that we may safely neglect it.

Mr. Jewell's contention that the evidences of vapor absorption could not be, and therefore were not, seen is practically equivalent to saying that a large diffuse nebula or star cluster cannot be seen at all unless the telescope be powerful enough to resolve it into stars. The fact is, the experienced observer would really select a telescope of rather low resolving-power as being the more efficient,—just as the experienced observer would select a spectroscope of rather low dispersion for observing the vapor bands in a planet's spectrum. However, he would put a large telescope in front of the spectroscope, rather than the opera-glass that has been suggested as a substitute.

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[1] *Pub. A. S. P.*, 6, 233.

One sentence as to the meteorological question brought up : a summer month on Mt. Hamilton would convince Mr. Jewell that his explanation of why there are fogs in our valleys is very insufficient.

W. W. CAMPBELL.

April 16, 1896.

CARL NICOLAUS ADALBERT KRUEGER.[1]

WE regret to record the death of Professor Dr. A. Krueger, Director of the Royal Observatory of the University of Kiel, and editor of the *Astronomische Nachrichten.*

Carl Nicolaus Adalbert Krueger was born in Marienburg, West Prussia, on December 3, 1832. After attending the Gymnasium of Elbing and later that of Wittenberg, he entered the University of Berlin in 1851, with the intention of studying astronomy. In the following year, however, he took up practical work as a voluntary assistant in the Observatory at Bonn, where he was appointed second assistant in 1853. Almost simultaneously with Krueger's appearance at the Bonn Observatory, the great work of the "Bonner Durchmusterung" was initiated by Argelander. With Schönfeld as his fellow observer, Krueger entered upon his part of this important undertaking with characteristic energy. Between 1852 and the beginning of 1859 he observed with the comet-seeker 810 zones out of a total of 1841 in the northern sky. Of the 476 revision zones observed between 1854 and 1861 he is to be credited with 304.

In spite of the great demands made upon his time by the work of observation and computation involved in the preparation of the Durchmusterung, Krueger found opportunity to pursue investigations in other fields. In 1853 he undertook the study of the motions of the minor planet Themis, whose perturbations by Jupiter enabled him to determine the mass of the latter planet. He also carried on observations of variable stars. In 1858 the heliometer previously used by Winnecke came into his hands, and was most successfully employed in a series of parallax determinations. Four years later he was appointed Professor of Astronomy and Director of the Observatory in Helsingfors, where he remained fourteen years, engaged in various theoretical and practical investigations. At the time of his appointment he married the eldest daughter of Argelander. The most important work of Krueger during his stay in Helsingfors, and later during the four years of his directorate at the Gotha Observatory, was the observation and reduction of 14680 star places in the zone 55° to 65° of the great catalogue of the Astronomische Gesellschaft.

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[1] For many of the facts embodied in this note we are indebted to an appreciative notice of Krueger's life and work, by Professor Dr. A. Auwers, in *A. N.* 3349.

The death of Peters in 1880 left the *Astronomische Nachrichten* without an editor. The exacting demands of this position made the choice of his successor a matter of grave concern, and the Astronomische Gesellschaft paid a fitting tribute to Krueger's worth by placing the editorial supervision of the foremost journal of astronomy in his hands. His work as editor began in 1881, shortly after his acceptance of the Professorship of Astronomy in the University of Kiel. The forty volumes which have appeared under Krueger's direction remain to testify to his editorial ability. The improvements effected by him will stimulate his successor to further efforts, and here, as in other fields, the influence of his life will long be felt.

THE TOTAL ECLIPSE OF THE SUN, APRIL 16, 1893.

REPORT AND DISCUSSION OF THE OBSERVATIONS RELATING TO SOLAR PHYSICS.[1]

THE memoir first gives reports by Mr. Fowler and Mr. Shackleton as to the circumstances under which photographs of the spectra of the eclipsed Sun were taken with prismatic cameras in West Africa and Brazil respectively on April 16, 1893. These are followed by a detailed description of the phenomena recorded, and a discussion of the method employed in dealing with the photographs. The coronal spectrum and the question of its possible variation, and the wave-lengths of the lines recorded in the spectra of the chromosphere and prominences, are next studied.

Finally, the loci of absorption in the Sun's atmosphere are considered.

The inquiry into the chemical origins of the chromospheric and prominence lines is reserved for a subsequent memoir.

The general conclusions which have been arrived at are as follows:

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[1] Abstract of a paper read before the Royal Society.

(1) With the prismatic camera, photographs may be obtained with short exposures, so that the phenomena can be recorded at short intervals during the eclipse.

(2) The most intense images of the prominences are produced by the H and K radiations of calcium. Those depicted by the rays of hydrogen and helium are less intense, and do not reach to so great a height.

(3) The forms of the prominences photographed in monochromatic light (H and K), during the eclipse of 1893 do not differ sensibly from those photographed at the same time with the coronagraph.

(4) The undoubted spectrum of the corona in 1893 consisted of eight rings, including that due to 1474 K. The evidence that these belong to the corona is absolutely conclusive. It is probable that they are only represented by feeble lines in the Fraunhofer spectrum, if present at all.

(5) All the coronal rings recorded were most intense in the brightest coronal regions, near the Sun's equator, as depicted by the coronagraph.

(6) The strongest coronal line, 1474 K, is not represented in the spectrum of the chromosphere and prominences, while H and K do not appear in the spectrum of the corona, although they are the most intense radiations in the prominences.

(7) A comparison of the results with those obtained in previous eclipses confirms the idea that 1474 K is brighter at the maximum than at the minimum Sun-spot period.

(8) Hydrogen rings were not photographed in the coronal spectrum of 1893.

(9) D_3 was absent from the coronal spectrum of 1893, and reasons are given which suggest that its recorded appearance in 1882 was simply a photographic effect due to the unequal sensitiveness of the isochromatic plate employed.

(10) There is distinct evidence of periodic changes of the continuous spectrum of the corona.

(11) Many lines hitherto unrecorded in the chromosphere and prominences were photographed by the prismatic cameras.

(12) The preliminary investigation of the chemical origins of the chromosphere and prominence lines enables us to state generally that the chief lines are due to calcium, hydrogen, helium, strontium, iron, magnesium, manganese, barium, chromium and aluminium. None

of the lines appear to be due to nickel, cobalt, cadmium, tin, zinc, silicon or carbon.

(13) The spectra of the chromosphere and prominences become more complex as the photosphere is approached.

(14) In passing from the chromosphere to the prominences, some lines become relatively brighter but others dimmer. The same line sometimes behaves differently in this respect in different prominences.

(15) The prominences must be fed from the outer parts of the solar atmosphere, since their spectra show lines which are absent from the spectrum of the chromosphere.

(16) The absence of the Fraunhofer lines from the integrated spectra of the solar surroundings and uneclipsed photosphere shortly after totality need not necessarily imply the existence of a reversing layer.

(17) The spectrum of the base of the Sun's atmosphere, as recorded by the prismatic camera, contains only a small number of lines as compared with the Fraunhofer spectrum. Some of the strongest bright lines in the spectrum of the chromosphere are not represented by dark lines in the Fraunhofer spectrum, and some of the most intense Fraunhofer lines were not seen bright in the spectrum of the chromosphere. The so-called "reversing layer" is therefore incompetent to produce the Fraunhofer spectrum by its absorption.

(18) Some of the Fraunhofer lines are produced by absorption taking place in the chromosphere, while others are produced by absorption at higher levels.

(19) The eclipse work strengthens the view that chemical substances are dissociated at solar temperatures.

J. NORMAN LOCKYER.

A NEW FIRM OF INSTRUMENT MAKERS.

WE take pleasure in calling attention to the establishment in Chicago of a new firm of instrument makers. Messrs. Kandler & Gaertner, the members of the firm, have had wide experience in the design and construction of instruments of research. Mr. Kandler was employed for many years in the workshops of Starke & Kamerer in Vienna; previous to his connection with the Kenwood Observatory he was known in Chicago as the junior member of the firm of Seelig

& Kandler, manufacturers of surveying instruments. Mr. Gaertner is a graduate of the Fachschul für Mechaniker in Berlin, an institution established by the Gesellschaft für Optik und Mechanik for the purpose of training instrument makers. He has been connected with several European and American workshops of the first class, including those of A. Repsold & Sons, Hamburg, the United States Coast and Geodetic Survey and the Smithsonian Astrophysical Observatory, Washington, and A. Hilger, London. During the past few months both members of the new firm have been engaged in the workshop of the Kenwood Observatory in constructing various special instruments for astronomical and astrophysical research. Having had this opportunity to become familiar with their work, we gladly recommend Messrs. Kandler & Gaertner to those who desire to have instruments constructed or repaired. On account of the difficulty of getting bolometers made elsewhere, it is worth while to mention that Mr. Gaertner is very skilful in constructing them.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

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THE

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THE NEW ELEMENTS OF CLÈVEITE GAS.

By J. R. Rydberg.

The excellent investigations of Runge and Paschen on the spectrum of clèveite gas[1] have made the existence of another new element besides helium very probable.[2] But the method of forming the spectral series seems to rest upon rather an insecure basis, although by the help of the relation between the principal series and the sharp series (second subordinate series of Kayser and Runge), which I long ago pointed out, it would have been very easy to state clearly the true connection. The relation in question, which comprehends the above mentioned series in a single common formula, is derived from the observation that the first term of a principal series forms at the same time the first term of the corresponding sharp series, or, to state the same thing in another form —

The difference between the common limit of the nebulous and the sharp series and the limit of the corresponding principal series gives the wave-number[3] *of the common first term of the sharp and the principal series.*

If we designate the limits of the series by D (nebulous), S

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[1] Astrophysical Journal, 3, 4–28, 1896.

[2] For the new elements I use the symbols A (Argon), He (Helium), Pa (Parhelium).

[3] By *wave-number* I mean the number of waves in 1^{cm}. See *Svenska Vetensk. Akad. Handl.*, 23, 35, 1890.

(sharp), *P* (principal series), the order of the series by subscripts to the symbols of the elements (stronger series 1, weaker 2), and the mean of *D* and *S* by *M*, we have for the alkali-metals:

	D	S	M	P
Li	28582.92	28582.16	28582.54	43482.53
Na$_1$	24468.89	24471.36	24470.13	41452.61
Na$_2$	24486.08	24488.55	24487.32	41452.61
K$_1$	21959.52	21951.39	21955.46	35008.92
K$_2$	22017.37	22009.24	22013.31	35008.92
Rb$_1$	20861.25	20877.05	20869.15	33706.66
Rb$_2$	21098.83	....	21098.83	33705.59

Hence, if we call P_1 the first term of a principal series, we have

	P—M	P$_1$	Diff.
Li	14899.99	14903.03	— 3.04
Na$_1$	16982.48	16972.70	+ 9.78
Na$_2$	16965.29	16955.51	+ 9.78
K$_1$	13053.46	13041.72	+ 11.74
K	12995.61	12984.63	+ 10.98
Rb$_1$	12837.51	12798.95	+ 38.56
Rb$_2$	12606.76	12575.18	+ 31.58

For Pa and He, on calculating the limits by the same method which I have used for the other elements, I have found the following values:

	D	S	M	P
Pa	27174.47	27175.00	27174.74	32032.53
He	29222.70	29222.63	29222.67	38452.89

where the connection of the series is still undecided. By using the above mentioned relation in the calculation of the values of P_1, two combinations present themselves, *viz.*,

	P	M	P—M	P$_1$ Obs.	Diff.	Mean error
Pa	32032.53	27174.74	4857.79	4900.65	— 42.86	20
He	38452.89	29222.67	9230.22	8950.14	+ 280.08	40
and						
Pa	38452.89	27174.74	11278.15	....	....	..
He	32032.53	29222.67	2809.86	....	....	..

Although the calculated values of P_1 differ very considerably from the observed values, there can be no doubt that the first combination, which is the one chosen by Runge and Paschen, is the only possible one, for the lines calculated from the second were not observed. We meet here with the not very common case in which the calculated values greatly surpass the observations in accuracy, the limits of error for the values of M and P amounting at most to one unit, while the mean errors of the two values of P_1, determined with the bolometer, are 20 and 40 respectively. The differences found certainly exceed the errors to be expected, but the analogy with the spectra of the alkali-metals speaks so decisively in favor of an exact agreement between the values of P_1 and $P—M$, that I do not hesitate to ascribe the differences to errors of observation.

In order to judge better of the possibility of such differences I have examined the observations of Runge and Paschen, first reducing to wave-lengths the extreme values of the angular determinations (Runge and Paschen, p. 27). Thus we find:

Observed maximum	Observed minimum	Mean	Calculated value
21040	19500	20400	20580.0
11450	10540	11170	10831.0

whence it appears that the calculated values lie within the limits of the observations. A closer examination shows that the angular determinations group themselves about well-defined means, by no means symmetrically, but so that the greater values are much more numerous than the smaller ones, and at the same time more distant from the closely concentrated central groups At the line 11170 we even find two distinct groups. The distribution of the values is shown in the table on page 94.

The greater deviation of the larger values seems to indicate a broadening of the lines in the direction of the shorter wave-lengths. But, however this may be, the arithmetical mean of the observations under these circumstances gives by no means the most probable value of the quantity in question. I have there-

Wave-length according to R. and P.	Number of values	Range in angular values	Mean wave-length	Number of greater values	Number of smaller values	Difference from mean	
	of the central group					of greatest value	of smallest value
20400	7	0'.10	20580	12	3	2'.63	1'.17
11170_1	7	0'.15	11350	5	1	2'.32	0'.28
11170_2	9	0'.18	11190	4	2	1'.87	0'.73
7280	7	0'.10	7330	7	3	2'.82	0'.48

fore calculated the mean angular values of the central groups, and with the aid of the table (*loc. cit.*, p. 25), deduced the mean wave-lengths. For the first line the value thus obtained coincides exactly with the number calculated above; this, however, must be regarded as partly accidental. The third line does not agree as well as before, but still falls within the limits of the errors of observation. As to the second line, the doubling of the central group agrees perfectly with an hypothesis which had suggested itself previously and quite independently to explain the considerable discrepancy between observation and calculation. According to Runge and Paschen the strong Na lines in the visible and ultra-violet spectrum come out with great intensity; it could therefore scarcely be doubted that the line 11392.5 in the infra-red would also appear. It was also to be expected that in the bolometric determinations this line would form with the adjacent 10831.0 a single thermal maximum, and retain only a feeble indication of its double origin; the two thermal maxima, if they are still to be discerned as separate lines, ought at all events to appear very close together on account of the superposition.

But this is just what we have found, for according to Runge and Paschen the general mean of the wave-length determinations gives the value 11170, which would come out as the mean of the two wave-lengths mentioned above, if the intensity of the Na line were 1.5 times as great as that of the He line. The two values which I have calculated from the central groups of the observations would indicate a sharp Na line and a broad He line. The determinations do not, however, allow any perfectly definite conclusions to be drawn. But I believe that the preceding considerations will suffice to prove the importance of making further measures of the two infra-red lines. The accuracy attained by Lewis in his bolometric measurements[1] would be quite sufficient to decide the present question. At all events I do not doubt that the calculated values 4858 and 9230 will be found for the wave-numbers of the lines *in vacuo*.

In this connection I cannot refrain from mentioning that the two new elements of clèveite gas as well as argon seem to be subject to a regularity regarding their atomic weights, to which I called attention some years ago.[2] The rule in question may be expressed as follows:

If the atomic weights of the elements, which form the first rows of the periodic system, be reduced to the nearest integral numbers, the elements of uneven valency will have the form 4n–1 and the elements of even valency the form 4n.

On account of the uncertainty of the determinations of atomic weights and their increasing differences from integral numbers, the rule could be traced with some certainty only for the first 22 elements (to Fe inclusive). It shows here three exceptions, *viz.:* Be (9 instead of 8), N (14 instead of 15) and Sc (44 instead of 43), but it gives place for He (4) and A (20) as well as for an element with the atomic weight 3, which would possibly answer to Pa. Spaces remain for elements with the reduced atomic weights 36, 44 and 47. The series of numbers is shown in the table on page 96.

Of the six places formerly vacant in the present division two are probably permanently taken up by the new elements, He and A. According to analogy these elements should have an even valency, while Pa might possess an atomic weight 3 and an uneven valency. For further particulars, as well as for regularities which appear on advancing further in the series of the elements, I will refer to the paper mentioned above. It seems not quite impossible that the present exceptions may yet submit to the rule, when we consider the imperfection of our knowledge of the metals of the so-called rare earths (Be and Sc) and keep in view the surprising discoveries of the impurities of nitrogen.

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[1] LEWIS, ASTROPHYSICAL JOURNAL, 2, 1–25, 1895.

[2] *Svenska Vetensk. Akad. Handl.* 11, No. 13, 1886.

n	1	2	3	4	5	6	7
Element	Pa	Li	B	N	Fl	Na	Al
P	?	7.01	10.9	14.01	19.06	22.995	27.04
4n — 1	3	7	11	(15)	19	23	27
Element	He	Be	C	O	A	Mg	Li
P	4.0	9.03	11.97	15.96	19.94	24.3	28.3
4n	4	(8)	12	16	20	24	28
n	8	9	10	11	12	13	14
Element	P	Cl	K	Sc	—	V	Mn
P	30.96	35.37	39.03	43.97	—	51.1	54.8
4n — 1	31	35	39	(43)	47	51	55
Element	S	—	Ca	—	Ti	Cr	Fe
P	31.98	—	39.91	—	48.0	52.0	55.88
4n	32	36	40	44	48	52	56

It is hardly possible that the approximation of the atomic weights to integral numbers, the correspondence in the numbei of elements in the two series of different valencies, and in the simultaneous evenness and unevenness of the integral numbers and the valencies, can be a mere chance.

The vacant places which still exist between Sc and Ti, as wel as between the corresponding terms of the following periods, seem only to add further support to the rule proposed, inasmuch as they afford very necessary space for the numerous metals of the rare earths.

UNIVERSITY OF LUND.

OUTLINES OF A THEORY OF SPIRAL AND PLANETARY NEBULÆ.

By E. J. Wilczynski.

The remarkable objects known as spiral nebulæ early attracted the attention of astronomers. There can be no doubt that they represent an important stage in the development of stellar systems. In this paper I shall attempt, without making any hypotheses, to explain their peculiar form. A number of other results will be obtained, and the general process of the evolution of nebular systems will present itself, but the full discussion of these interesting subjects must be reserved for another occasion.

This theory presented itself to me while engaged in investigations of quite a different kind, and it will be useful if we start out from the same point of view. If a swarm of meteors, say spherical in the beginning, revolves around the Sun, according to Schiaparelli, one of two things can happen. Either the mutual attraction of the meteors is great enough to resist the dissolving influence of the Sun, or this is not the case. In the latter case the dissolution will take place, and finally a ring of meteoric matter will result, filling the entire orbit.

If we examine more closely how this spreading out of the swarm into a ring is effected, we find some remarkable results. If, for the sake of simplicity, we assume that the swarm's center of gravity describes a circle around the Sun, we can also assume that all of the individual particles describe circles. For the dissolution can only take place if their mutual attraction is very small, and the act of dissolution itself diminishes the disturbing influence of their mutual attraction, by increasing the distances. Obviously all particles which describe the same circle constantly maintain their relative positions, but the particles in two different circles are in motion relative to one another. Let A and B (Fig. 1) be two points, whose orbits have the radii a and b res pectively, where *a* is smaller than *b*. According to Kepler's third law, *A* will complete its circle sooner than *B*, so that when *B* has returned to its original position, *A* will be at *A'* instead of at *A*. After *B* has completed two revolutions *A* will be at *A''*, etc. Obviously the straight line *AB* is thus gradually spread out into a spiral whose coils continually multiply and approach each other. Similarly every straight line of the original swarm is changed into a spiral, whose equation it would be easy to deduce.

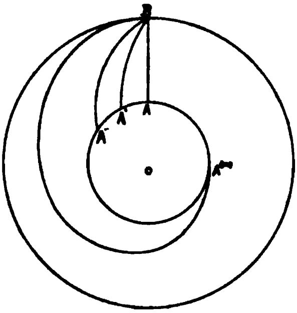

FIG. 1.

The number of coils *n* obviously depends upon the time which has elapsed since the beginning of the process. If we assume that the motion takes place according to Kepler's third law, if *a* and *b* are the radii of the circles between which the entire spiral lies, and if ω_1 denotes the angular velocity of rotation for the inner circle, we have the following expression for the time which has elapsed since the beginning of the disintegration:

$$t = \frac{2n\pi}{\omega_1} \frac{1}{1 - \left(\frac{a}{b}\right)^{\frac{3}{2}}}.$$

The application of these results to spiral nebulæ is obvious. If in any irregular nebulous mass whatever a center of attraction has been formed, all long streaks and irregular masses of nebulous matter which remain, being subject to the law of gravitation, must in the course of time assume a spiral form. Only those masses are excepted herefrom which are great enough to resist the dissolving influence of the center of attraction. Obviously our theory offers a possibility *of computing the time during which the nebula exists as a spiral.*

It must not be supposed from the above that we assume the nebulæ to consist of meteors. If we assume a gaseous constitution for them the results remain essentially the same. The attempt to prove this has led to the investigations contained in the following paper, ("Hydrodynamical Investigations of the Solar Rotation,") the application of which to the present case is easy to understand.

The theorems which are demonstrated there are of importance in the theory of planetary nebulæ. If the nebula (supposed gaseous) has the shape of a flat disk, if ω denotes the angular velocity of rotation, and ρ the density at the distance r from the center, where ω and ρ are supposed to depend only upon r, then

$$\frac{d^2\rho}{dr^2}+\frac{1}{r}\frac{d\rho}{dr}-\frac{1}{\rho}\left(\frac{d\rho}{dr}\right)^2+\frac{4\pi}{c}\rho^2=\frac{\rho}{c}\left(2\omega^2+r\frac{d\omega^2}{dr}\right).$$

This equation shows that in a planetary nebula of the above kind, whose temperature is the same throughout, the law of density $\rho=f(r)$ can be found if the law of rotation $\omega=g(r)$ is known, and conversely. In the first case we get two, and in the second case, one constant of integration. Now, $\rho=f(r)$ can frequently be obtained by measuring the brightness of the different parts of the nebula. We can therefore find ω, and would be able to determine the entire motion of the different parts of the nebula if we knew the value of ω for any one value of r. *We therefore have here an indirect method for observing motion in nebulæ.*

Further discussion of this and similar questions, as well as of the practical value of these results, whose theoretical value appears to me beyond doubt, must be deferred for the present. I believe that a discussion of photographs of nebulæ from this point of view would be of great interest.

With regard to the spiral nebulæ, I must add that many years ago Steven Alexander[1] held views which resemble the above in some particulars. Of all authors which I have been able to consult, Alexander is the only one whose explanation can be called scientific, while all others are more or less fanciful.

BERLIN, January 1896.

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[1] STEVEN ALEXANDER, *Ast. Jour.*, 2.

HYDRODYNAMICAL INVESTIGATIONS OF THE SOLAR ROTATION.

By E. J. WILCZYNSKI.

SINCE the observations of Carrington first proved the remarkable law of the Sun's rotation, the observational material has greatly increased and the subject has been discussed by many eminent astronomers, among whom I will mention only Spoerer, Zöllner, Faye, and Tisserand. Theories have been proposed by Zöllner and Faye, which are far from being satisfactory. A memoir by Roche[1] on this subject is inaccessible to me. More recently Harzer[2] and Wilsing[3] have taken up the investigation, and doubtless they have found the correct method of treating the question. But their mathematical treatment is extremely complicated, and lacks rigor. The following investigation, which was completed before I knew of Harzer's and Wilsing's work, not only gives a perfect explanation of the solar rotation, but allows a great number of other questions to be put and partly answered, which have been hitherto considered unanswerable.

Let x, y, z be the rectangular coördinates of any point of a fluid, and a, b, c the values of x, y, z for a certain time $t = 0$. All of the points attract each other according to Newton's law of gravitation, so that a certain force acts upon every point. Let V be the potential of this force. Then, according to Lagrange's equations of hydrodynamics, we have:

$$\left.\begin{aligned}
\frac{d^2 x}{dt^2}\frac{dx}{da}+\frac{d^2 y}{dt^2}\frac{dy}{da}+\frac{d^2 z}{dt^2}\frac{dz}{da}&=\frac{d(V-P)}{da}\\
\frac{d^2 x}{dt^2}\frac{dx}{db}+\frac{d^2 y}{dt^2}\frac{dy}{db}+\frac{d^2 z}{dt^2}\frac{dz}{db}&=\frac{d(V-P)}{db}\\
\frac{d^2 x}{dt^2}\frac{dx}{dc}+\frac{d^2 y}{dt^2}\frac{dy}{dc}+\frac{d^2 z}{dt^2}\frac{dz}{dc}&=\frac{d(V-P)}{dc}
\end{aligned}\right\}\qquad(1)$$

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[1] ROCHE, *Mémoires de l'Académie des Sciences*, etc., Montpellier, Tome IX.

[2] HARZER, *A. N.*, 3026.

[3] WILSING, *A. N.*, 3039.

in which we have put

$$P = \int \frac{dp}{\rho}, \qquad (2)$$

where p denotes the pressure, and ρ the density for the point x, y, z. In addition to these equations we have:

$$\frac{d(\rho D)}{dt} = 0, \qquad (3)$$

where

$$D = \begin{vmatrix} \frac{dx}{da}, & \frac{dx}{db}, & \frac{dx}{dc} \\ \frac{dy}{da}, & \frac{dy}{db}, & \frac{dy}{dc} \\ \frac{dz}{da}, & \frac{dz}{db}, & \frac{dz}{dc} \end{vmatrix} \qquad (4)$$ [1]

It must be noted that the general term fluid includes the incompressible fluids and gases as special cases.

We will now assume that the whole mass is in rotation about the axis of z, so that

$$x = \sqrt{a^2 + b^2} \cos \omega t, \; y = \sqrt{a^2 + b^2} \sin \omega t, \; z = \text{const.} = c, \qquad (5)$$

where ω is the angular velocity of rotation, which need not be the same everywhere, but depends upon a, b, c. From (5) we find by differentiation:

$$\begin{cases} \frac{d^2 x}{dt^2} = -\omega^2 \sqrt{a^2 + b^2} \cos \omega t, \text{ etc.} \\ \frac{dx}{da} = \frac{a}{\sqrt{a^2 + b^2}} \cos \omega t - \sqrt{a^2 + b^2}\, \frac{d\omega}{da}\, t \sin \omega t, \text{ etc.,} \end{cases}$$

and all derivatives of z are zero, except $\frac{dz}{dc}$, which is equal to unity. If we substitute these values in (1), a simple reduction gives

$$\frac{d(V-P)}{da} = -\omega^2 a, \quad \frac{d(V-P)}{db} = -\omega^2 b, \quad \frac{d(V-P)}{dc} = 0. \qquad (6)$$

These equations show that $V - P$ does not depend upon c, and depends upon a and b only in so far as these quantities are contained in

$$r = \sqrt{a^2 + b^2} = \sqrt{x^2 + y^2}.$$

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[1] *Cf.*, for instance, Kirchhoff's *Vorlesungen über Mechanik*.

The same result is manifestly true for ω^2, *i. e.*, ω^2 *is a function of* r *alone*. All conditions are then satisfied, for it is easy to prove that D vanishes, so that (3) is also satisfied.

From (6) we now deduce:

$$\frac{d(V-P)}{da}=\frac{d(V-P)}{dr}\frac{a}{r}=-\omega^2 a\,,$$

whence

$$V-P=-\int\omega^2 r\,dr. \tag{7}$$

According to Poisson's equation

$$\Delta V=\frac{d^2V}{dx^2}+\frac{d^2V}{dy^2}+\frac{d^2V}{dz^2}=-4\pi\rho\,.$$

Consequently we find from (7):

$$\begin{aligned}-\Delta(V-P)&=+4\pi\rho+\Delta P\\ &=+\Delta\Big[\int\omega^2 r\,dr\Big]=2\omega^2+r\frac{d\omega^2}{dr}.\end{aligned} \tag{8}$$

If the fluid is a gas, we have Mariotte's law:

$$p=\alpha^2\rho, \qquad P=\int\frac{dp}{\rho}=\alpha^2\log\rho\,, \tag{9}$$

where α^2 is a constant depending upon the nature of the gas and upon the temperature. If the absolute temperature T is not the same throughout, and if we assume the fluid to be gaseous, we have:

$$p=c\rho T, \qquad P=c\int\rho\frac{dT+Td\rho}{\rho}=cT(1+\log\rho). \tag{9a}$$

For (8) we shall then have

$$4\pi\rho+c\Delta T+c\Delta\log\rho=2\omega^2+r\frac{d\omega^2}{dr}\,, \tag{10}$$

which for the case of constant temperature reduces to

$$4\pi\rho+c\Delta\log\rho=2\omega^2+r\frac{d\omega^2}{dr}\,, \tag{10a}$$

an equation from which it is easy to deduce the one employed in our theory of planetary nebulæ.

Let us now identify our rotating mass with the Sun, which we will suppose to be spherical. According to our first result, ω depends only upon r, *i. e.*, all points whose perpendicular distance from the axis of rotation is the same have the same velocity of rotation. If we therefore regard the axis of rotation to be surrounded by a system of cylinders, all of the points situated upon the surface of one of these cylinders rotate with the same velocity. In other words, these cylindrical surfaces rotate as if they were solid. But from one cylinder to another ω changes according to a certain law, $\omega = f(r)$, which, according to (10), depends upon the distribution of temperature and pressure in the Sun's interior. Since we know nothing of these quantities, *it is impossible to deduce theoretically a formula for the solar rotation.* We cannot, therefore, agree with Herr Harzer that his formula is more than an empirical law.

But it is very important to note that if $\omega = f(r)$ is known from observation, *equation* (10) *gives a condition which the temperature and density of the solar interior must satisfy.* If it were possible to find a second condition of this kind, *it would be possible to find the laws according to which these quantities vary from point to point.* If the periodicity of the Sun-spots is a hydrodynamic phenomenon, such an equation would follow from it. To obtain the numerical values of temperature and density everywhere, it would still be necessary to know a number of constants, *viz.*, temperature and density upon any surface of constant temperature or density, and the Sun's mass, which is known. This gives the value of the integral

$$M = \int\int\int \rho \, dx \, dy \, dz \, .$$

Obviously the influence of friction, which we have neglected, will be a tendency toward uniform rotation. It is evident, however, that an enormous time is necessary before its influence becomes noticeable. It is this point with which Wilsing's paper is principally concerned.

There is one other point to which I would like to call attention. It has recently been established by Stratonoff[1] that the faculæ have a different law of rotation from the spots, so that in every latitude the spots rotate more slowly than the faculæ. This is perfectly in harmony with the above theory, if we assume that the faculæ occupy a higher level in the Sun than the spots. If S

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[1] STRATONOFF, *A. N.*, 3344.

and F are a spot and a facula respectively in the same heliographic latitude ϕ, F is at a greater distance from the axis of rotation than S, and since the law of rotation is such that ω increases with the distance r, F must rotate more rapidly than S. Obviously the comparison of the spot rotation law with that of the faculæ gives a means for determining the difference in the altitude of spots and faculæ or SF. The present material seems to indicate that this difference is considerable, almost $\frac{1}{30}$ of the solar radius. A similar comparison between the rotation of the spots and that of the photosphere as given by Dunér's spectroscopic observations indicates that *the spots are at a higher level than the photosphere.* The depth of the solar atmosphere between the photosphere and the faculæ is therefore probably very considerable, a result which agrees with the recent investigations of Messrs. Jewell, Humphreys and Mohler, who have likewise assigned a great depth to the reversing layer.

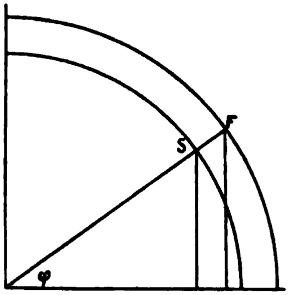

FIG. 2.

The full discussion of these questions must be deferred for the present. The Sun's law of rotation has not only been explained in a general manner, but we have been able to deduce important consequences from it. As for the main phenomenon itself, we now see that it would be a rather surprising fact if the Sun rotated like a solid mass, because this is only one of an infinite number of possible cases. The manner of the solar rotation is not to be wondered at, but it gives us a glimpse of the possibility of learning more about the Sun's interior condition.

BERLIN, January 1896.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XIV.[1]

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character
2975.587	Cr	o
2975.766		ooo
2976.036		o Nd?
2976.191		ooo
2976.316		ooo
2976.801		ooo
2977.021		oo Nd?
2977.331		ooo N
2978.151		ooo N
2978.316		oooo N?
2978.670		ooo N
2979 480		oo
2979.670		oooo N
2979.860		o N
2980.080		o Nd?
2980.330		oo
2980.490		ooo
2980.690	Cd?	oo
2980.915	Cr	o
2981.070		oo N
2981.990		ooo N
2982.180		oo
2982.340		ooo N
2982.530		oo N
2982.885		ooo
2983.649[2] s	Ca, Fe?	oooo N
2983.764		ooo N
2984.414		oooo
2984.654[3]		oo
2984.849[3]		ooo N d?
2985.119[4]		ooo N d?
2985.359		oooo N
2985.439		oooo N
2985.629		ooo
2985.999	Cr?	ooo
2986.109	Cr	ooo
2986.239		ooo
2986.379		ooo
2986.579	Cr	o
2986.749		oo N
2986.999		oooo
2987.169		ooo
2987.289		ooo
2987.439 s	Fe?	ooo
2987.959		oooo N
2988.144		oo N
2988.333		ooo N
2988.598		ooo
2988.733	Cr	oo
2988.873		ooo
2989.038		o N
2989.298		oo
2989.523		ooo
2989.708		1
2989.828		ooo
2990.008		ooo
2990.173		oo
2990.438		o
2990.523	Fe?	1
2990.718		oo
2990.788		ooo
2990.968		oo
2991.203		o
2991.318		oooo
2991.538		ooo
2991.738		oo
2992.188		ooo Nd?
2992.488		oooo

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[1] When the publication of the Table was commenced in the first volume of this JOURNAL, the calculations of wave-lengths in the extreme ultra-violet was not completed. These wave-lengths will be published in this and subsequent numbers of the JOURNAL.

[2] Strong line of iron at 2983.689. The strong *shaded* lines of iron and some other elements are with difficulty seen in the faint beginning of the ultra-violet solar spectrum, and as a consequence their intensities are much less than in corresponding metallic spectra.

[3] Violet portion of line partly due to a line of overlapping yellow.

[4] Red portion of line partly due to a line of overlapping yellow.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
2992.693	Ni	0	3002.433		000
2992.828		0000	3002.593	Ni	00
2993.027		000	3002.743	Fe,-	00
2993.177		000	3003.102	-, Fe	0 N
2993.327		000	3003.182		1 N
2993.457		000	3003.312		000
2993.807		0000	3003.572		0 Nd?
2993.927		00	3003.773[1]	-, Ni	2 Nd?
2994.177	Cr	00	3003.962		00
2994.327		000 N	3004.230		00
2994.527 s	Fe, Ni	000	3004.572		000
2995.057 s	Ca	000	3004.732		1
2995.212	Cr, Co	00	3004.912		000 N
2995.347		000	3005.160 s	Cr	3
2995.597		00	3005.407 s	Fe?,-	3
2995.767[3]		00	3005.572		000 Nd?
2995.937		000	3005.852	-,Co?	2 d
2996.096		2	3006.059		0
2996.187		000	3006.262[2]		0 Nd?
2996.347		0000	3006.482		000 Nd?
2996.495	-, Fe?	2	3006.677		0 Nd?
2996.689	Co?, Cr	1	3006.982 s	Ca	0
2996.940		1	3007.237 s	-,Fe	1 N
2997.067		000	3007.405 s	Fe	1 Nd?
2997.317		00	3007.592		00 N
2997.437 s	Ca, Cu?	2	3007.757	Mn?	00
2997.602		000	3007.862		000
2997.787		00 N d?	3008.072		000
2998.066		0	3008.212 s	Fe	00
2998.266		00	3008.312	Mn?	00
2998.451		0	3008.582		00 N
2998.606		00	3008.744		0 Nd?
2998.776		000	3008.914		00
2998.916	Cr	2	3009.022		0000
2999.136		0000	3009.190	Fe?	1
2999.286		00	3009.302 s	-,Ca	1
2999.603 s	Fe,-	00 N	3009.462		00
2999.748 s	Ca	0	3009.642 s	-,Fe	2 N
2999.923		000	3009.822		1 N
3000.043		000	3010.277		0
3000.178		00	3010.522		00
3000.458		00	3010.731		0
3000.553	Fe,-	00	3011.257	Mn?	00 N
3000.693	Co,-	00	3011.390		00
3000.913	Ti?, Ca	000	3011.527		00
3001.103 s	Cr, Fe	00 Nd	3011.597	Fe	1 N
3001.373		00 Nd	3011.747		000
3001.763		000	3011.832		00
3002.093		000 N	3011.907		00 N
3002.288		000	3012.146[2]	Ni,-	5 d?

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[1] Red portion of line partly due to a line of overlapping yellow.

[2] Violet portion of line partly due to a line of overlapping yellow.

[3] Very strong shaded iron lines.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3012.247		000 N	3020.936		000 N
3012.557 s		2	3021.170[2,3] s	Fe	3
3012.707		000	3021.346		000 N
3012.827		000 N	3021.516		0000 N
3013.037		0	3021.676	Cr	1
3013.169	Cr?	1	3021.821		0000 N
3013.227		0	3022.001		000 N
3013.437		00 Nd?	3022.216		0000Nd?
3013.691	Co	00	3022.371		00
3013.840	Cr	1	3022.476	Co	0
3014.067		000	3022.693		1
3014.215 s		0	3022.861	-,Mn	1
3014.282		1	3023.011		0000
3014.427		00	3023.178[2]		2 N
3014.552		000 N	3023.416		000
3014.752	Mn?	000	3023.559		00 N
3014.878		1	3023.796		000 N
3015.049	Cr	1	3023.984		0 Nd?
3015.300	Cr	2	3024.156 s	Fe,-	4 Nd?
3015.467		000	3024.326		000
3015.617		2	3024.465 s	Cr	4
3015.799	Co	000	3024.756		000 Nd?
3015.917		000	3024.908		1
3016.047	Fe?-	2	3025.095		1 Nd?
3016.300 s	Fe,-	4 Nd	3025.385 s		3
3016.557	Mn?	00	3025.571		0000 N
3016.622		000	3025.737	-,Fe?	2 N
3016.869		2	3025.961 s	Fe	2 N
3016.957		1	3026.131		00 N
3017.127		0000	3026.331		000 N
3017.308	Ti?	1	3026.486	Co	0
3017.361	Co?	0	3026.591	Fe,-	3
3017.516		0	3026.761		2
3017.691	Co, Cr	1 Nd?	3026.931		1
3017.786 s	Fe,-	1 N	3027.069		0
3017.961		00	3027.141		0
3018.086		000 N	3027.291 s	Fe	000 N
3018.248		1	3027.481		000 N
3018.361		00	3027.717		0
3018.601	Cr,-	2	3027.811		1
3018.919	Cr	1	3027.999		000 N
3019.078 s	-, Fe	1 N	3028.128[2]		3
3019.271	Ni	1 N	3028.243		1
3019.426		1	3028.403		00
3019.666		0000	3028.561		00 Nd?
3019.986		00 N	3028.716		0
3020.106		0 N	3028.806		0
3020.346		000 N	3028.980		1
3020.606[3] s	Fe	00 N	3029.134		1 Nd?
3020.826[3] s	Cr, Fe	00 Nd?	3029.261	Cr	1

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[2] Violet portion of line partly due to a line of overlapping yellow.

[3] Very strong shaded iron lines.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3029.369	Fe?-	3	3037.510 s	Fe	10 N
3029.441		0 N	3037.685		0
3029.661		000	3037.895		0
3029.835	Ti?	4	3038.050	Ni	3
3029.936		000	3038.210		1
3030.091		1	3038.423	Co?,-	2
3030.261	Fe	3	3038.625		1
3030.356	Cr	2	3038.860		3
3030.591		000	3039.095		1
3030.720		1	3039.170		2
3030.881		000 N	3039.309		0000
3031.046		1	3039.433		2
3031.161		0	3039.660		0
3031.312	Fe	1	3039.721	Co,-	2
3031.454	Co, Cr	1	3039.883	Cr	2
3031.591	Cr?	00 N	3040.030		0000
3031.741	Fe	1	3040.130		000
3031.821		1	3040.340		0000
3031.975	-,Ni?	3	3040.435		1
3032.141		0000	3040.550	Fe	3
3032.336		000 N d?	3040.712	Mn	1
3032.567		1	3040.865		0
3032.741		0000	3040.950	Cr	2
3032.971		0000	3041.060		2
3033.026		3	3041.145		0
3033.211		2	3041.325	Mn?	00 N
3033.321		0000	3041.532		0 Nd?
3033.532		5	3041.740	Fe	2
3033.718		0	3041.867	Fe	2
3033.918		2	3042.005		00
3034.036		000	3042.150	Fe	3
3034.166		00	3042.365		0
3034.304	Cr	2	3042.592	Co	0
3034.558	Co,-	2	3042.765	Fe	3
3034.669		3	3042.957		0
3034.911		00	3043.239		0
3035.098		0	3043.456	Mn?	1
3035.341		0	3043.648		1
3035.468		1	3043.870	Mn?	0000
3035.581		000 N	3043.970		1
3035.847 s		5	3044.112 s	Co	3
3036.001		00	3044.220		000
3036.215	Ca?	0	3044.345		0
3036.370		00	3044.442		0000
3036.505		0	3044.671 s	Mn	3
3036.625		00	3045.100	-,Ni	3 } d
3036.880		1 Nd?	3045.183	Fe	4 }
3037.085		00	3045.440		000 N
3037.160	Cr	2	3045.560		0000 N
3037.330		1 N	3045.695	Mn,-	3

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3045.870	-,Mn?	2 N	3053.856		1
3046.025		0000	3053.988	Cr	3
3046.150		0	3054.429	Mn, Ni	10
3046.375		00	3054.807	-,Co	1
3046.610		00	3054.931		0
3046.778 s	Ti,-	5	3055.051	Zr	0
3046.919		0	3055.233		0
3047.041		1	3055.374	Fe	4
3047.158	Mn	1	3055.428		2
3047.311		0	3055.563		0
3047.471		0 N	3055.701		0000
3047.725 s	Fe	20 N	3055.814 } s		2
3047.911		1 Nd?	3055.861		0
3048.151	,Co	0 Nd?	3056.021		0000 N
3048.327		1	3056.221		0
3048.440		000	3056.339		1
3048.563		3	3056.441		1
3048.701		000 Nd?	3056.691		0
3048.803		1	3056.861	Ti	2
3048.990	Mn, Co	2	3056.901		1
3049.124		0	3057.117		00 N
3049.261		00	3057.257		1
3049.462		3	3057.382		00
3049.649		2	3057.552 s	Ti, Fe	20
3049.856		000 N d	3057.753	Ni	2
3050.001		000 N	3057.907		1 N
3050.186 } s		2	3058.072		00
3050.251		4	3058.189	Ti	4
3050.374		0000	3058.457		1
3050.561		0000	3058.605		1
3050.623	Co	000	3058.812		0
3050.711		1	3059.012		1 N
3050.943	Ni	5	3059.212 s	Fe	20
3051.156		1	3059.377		0
3051.351		0000	3059.482		0
3051.528		2 N	3059.616		2
3051.721		000 N	3059.845	Ti	3
3051.896		00	3060.137	-,Co	1
3052.091		000 N	3060.192		00
3052.146		00	3060.337		00
3052.331	Cr?	0	3060.450		1
3052.486		0	3060.552		1
3052.591		1	3060.652	Fe?	1
3052.674		0	3060.727		1
3052.871		0	3060.878		2
3053.031		00	3061.093 s	Fe?	3
3053.113 [2]	Fe	4	3061.259 [1]		00 N
3053.341		000 N	3061.487	Zr	00 N
3053.526 [2]		7 d?	3061.682		0
3053.724		0	3061.772	Cr?	00

[1] [illegible] of line partly due to a line of overlapping yellow.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3061.931 s	Co	3	3069.288		2
3062.082		00	3069.441		1
3062.222	Mn	1	3069.562		2
3062.358	Co,-	4 N	3069.788		1
3062.622		00	3070.022		1
3062.795		00	3070.145		0
3062.969		3d?	3070.372	Mn	3
3063.152		0000	3070.487		00
3063.282		1	3070.599		1
3063.348		3	3070.802		0
3063.512	Cu	000	3070.902		0
3063.612		2	3071.112		00
3063.662		3	3071.252		1
3063.836		2	3071.360	Ti	3
3063.912		00	3071.542		00
3064.043	Fe?	2	3071.662	-,Ba	00
3064.122		1	3071.784		0
3064.323		2	3071.905		00
3064.475	Co	1	3072.072	Co	1
3064.622		000	3072.222	Ti	3
3064.729	Ni	3	3072.289		0
3064.802		1	3072.435	Co	3
3064.936		1	3072.602		1
3065.062		1	3072.777		000
3065.201	Cr?,-	2	3073.091	Ti,-	6 Nd?
3065.423		1	3073.232	Mn,-	1
3065.602		0000	3073.342		2
3065.722		00	3073.477		0000
3065.882		0000 Nd?	3073.632	Co	00
3066.101	-,Mn	2	3073.784	Cr	1
3066.251		0	3073.939	Cu,-	0
3066.334	Ti	2	3074.104	Fe?	1
3066.471	Ti	1	3074.262	Fe?	2
3066.608	Ti, Fe?	2	3074.492		1
3066.793		000	3074.542	Fe?	2
3066.923		000	3074.803		0
3067.101	Fe?	1	3075.012		000 N
3067.230	Fe	2	3075.142		000
3067.369 s	Fe	8	3075.242		0
3067.493		1 N	3075.346 s	Ti	3
3067.764		1	3075.462		0
3067.895		1	3075.562		0000
3068.046		2	3075.702		0 N
3068.283	Fe	2	3075.840 s	Fe	3
3068.388		1	3076.002		1
3068.583		1	3076.105		1
3068.705		1	3076.372		0
3068.832		1	3076.542		1
3068.903		0	3076.692		0000
3069.053		00	3076.857		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3076.938		0	3083.957		00
3077.134		0	3084.162		00
3077.295 s	Fe	3	3084.272		0000
3077.332 s		1	3084.397		000
3077.502		0000 Nd?	3084.562		0
3077.665		0	3084.682	Cr?	00
3077.747		1	3084.792		0000
3077.842	Fe?	0	3084.902		0000
3077.942	Cr	0	3085.004		1
3078.151 s	Fe?	4 d?	3085.150		0
3078.359		0	3085.313		2
3078.494		2	3085.438	Fe?	1
3078.552	Fe	3	3085.502		1
3078.769 s	Ti,-	8 d?	3085.652		0000
3078.932		000	3085.780		1
3079.022		00	3085.827		1
3079.212		000 Nd?	3085.972		000
3079.415		00	3086.102		000 N
3079.482	Co	0 N	3086.217		000
3079.724 s	Mn	2	3086.335		0
3079.862		0000	3086.503	Co	1
3079.932		000	3086.636		2
3080.086	Fe?	4	3086.742		00
3080.223	Fe?	1	3086.893 s	Co	4
3080.352		0	3087.094		000
3080.475		1	3087.182 s	Ti	1
3080.529		00	3087.451		1
3080.702		00	3087.559		0
3080.864 s	-,Ni	5	3087.639	Cr?	000
3080.984	Cd	00	3087.799		00
3081.112		1	3087.949	Co	0 Nd?
5081.354		2	3088.145 s	Ti	7 d?
3081.419	Mn,-	3	3088.294		0 N
3081.567		0	3088.461		1
3081.657		1	3088.716		00
3081.787		1	3088.858		2
3081.832		1	3088.929		0000
3081.947		0	3089.106		0
3082.142	Mn?	1	3089.202		000
3082.275 s	Al	5	3089.509	Ti	1
3082.632		00	3089.614		00
3082.734	Co	2	3089.719	Co	3
3082.957	Co	00 N	3089.851		2
3083.149		1	3089.974		2
3083.275		1	3090.328	Ti?, Fe?, Co	1 N
3083.389		1	3090.480		1
3083.489		00	3090.592		0
3083.610		0	2090.839		00
3083.727		00	3090.974		0
3083.859 s	Fe	4	3091.177	-,Mg	4

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3091.319		1 N	3097.935		000
3091.477		1	3098.070		000
3091.689	Fe	4	3098.177		0
3091.799		00	3098.298	Fe, Co	2
3091.976		0	3098.430		0000
3092.199		0	3098.560		000
3092.339		0000	3098.693		2
3092.509		1	3098.825		000
3092.579		00	3098.930		00
3092.704		0000	3099.073		00
3092.818 s	Al	4	3099.220	Ni,-	2
3092.957 s	Al	1	3099.340	Zr	0
3093.089	Mg	1	3099.523		1
3093.229		2 N	3099.680		0 N
3093.452	Fe	1	3099.780	Co	000
3093.604		0	3099.895		000
3093.714		00	3100.001 } s	Fe	3
3093.829		000	3100.092 }	Fe	3
3093.929	Fe	1	3100.255		00 N
3093.989		1	3100.430 s	Fe, Mn	4 N
3094.049	Fe, Cu?	000	3100.629		000
3094.174		0000	3100.787 s	Fe, Ti	3
3094.311		1	3100.944	Fe, Co?	1
3094.401		1	3101.047		0
3094.470		00	3101.117	Fe	1
3094.575		00	3101.347		1
3094.732 s		2	3101.522		00 N
3094.830		0000	3101.679 s	Ni	4 N
3095.003 s	Fe?,-	4	3101.799		00 N
3095.190		0	3102.000 s	Ni	3
3095.360	Fe	2	3102.079		00 N
3095.453		3	3102.253		1
3095.660		00 N	3102.404	V	3
3095.830	Co	00 Nd?	3102.474	-,Co	2
3095.990	Cr,-	0	3102.624		0000
3096.145		1	3102.748		0
3096.244		2	3102.869		00
3096.430		0	3102.987	Fe	1
3096.510	Co	0	3103.084		0
3096.655	Cr?	000	3103.214		0000Nd?
3096.730		0	3103.389		0
3096.870	Co,-	000 N	3103.454		1
3097.008	,-Mg	5	3103.599		00
3097.235	Ni	2	3103.719		0000
3097.282	Ti	1	3103.886	Co, Fe?	2
3097.460		000	3103.924	Ti, Fe?	3
3097.538		00	3104.087	-,Co	00
3097.595		00	3104.269		0
3097.723		00	3104.379		0000
3097.890		1	3104.454		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3104.676		2 N	3112.183	Fe, Ti?	2
3104.819		00	3112.320		1 N
3104.884		0000	3112.575	Ti?	00
3105.019		00	3112.715		0000
3105.199	Ti	2	3112.790		00
3105.279		1	3112.910		0000
3105.429		0000	3113.060		00
3105.569	-,Ni	2	3113.203		00
3105.668		1	3113.320		0000
3105.782		1	3113.490		1
3105.999	Co?	0000 N	3113.560	Co	0
3106.137		2	3113.698	Fe?	1
3106.346	Ti	3	3113.773		0
3106.664 s	Zr	2	3113.945		0 N
3106.914	Ti	000	3114.185	Ti?	1
3107.012		1	3114.232	-,Ni	3
3107.197	Co,-	00 N	3114.423		2
3107.427		0	3114.460		1
3107.564		0	3114.590		0000
3107.670		1	3114.735		00
3107.830	Ni?	0	3114.780		0
3107.959		00	3114.885		1
3108.089	Fe?	1	3115.150 s	Fe	1 N
3108.239		0000 N	3115.390		0
3108.369		00 N	3115.460		0
3108.469		0000	3115.575		0
3108.661	Cu?	00	3115.670		00
3108.787		0	3115.775		1
3108.991		0	3115.990		0
3109.057		1	3116.160		0000 N
3109.179		1	3116.370	Fe?	1
3109.439 s	-,Cr	3	3116.500		0
3109.609	Co	00	3116.610	Fe?	1
3109.729		1	3116.741	Fe	2
3109.909		0000	3116.835		1
3110.034		00	3117.025		0
3110.190	Co,-	1	3117.090		1
3110.351	Fe?	5 Nd?	3117.145		00
3110.635		00	3117.309		1
3110.810	Ti, V	5 Nd?	3117.357		0
3110.955	Co, Fe?	2	3117.540	Ti?	00 N
3111.000	Cr, Zr	1	3117.770	Ti, Fe?	2
3111.180		0000	3117.877		1
3111.285		00	3117.998		2
3111.410	Co?	00 N	3118.249	Ti?	1
3111.530		0000	3118.360	Co	0
3111.640		0000	3118.498	V	3
3111.791	Fe?	1	3118.665		00
3111.920	Fe?	2	3118.764	Cr,-	2
3112.050		00	3118.935		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3119.144		00	3126.319	V, Fe	5
3119.307	-,Cr	1 Nd?	3126.444		000
3119.460		00	3126.584		00
3119.613	Fe	3	3126.729		1
3119.787	Ti?, Cr	1	3126.879	Co,-	1
3119.911	Ti	1	3126.959		0
3120.121		00 N	3127.159		00
3120.201		0000	3127.229		000
3120.346		1	3127.359	Fe?, Co	0
3120.481	-,Cr	3	3127.474		0
3120.539	Fe	2	3127.604		0
3120.711		000	3127.784		2 d?
3120.841	Zr	0	3127.959		1
3120.986	Fe?	1	3128.199		0 N
3121.191		0000	3128.402		1
3121.270 s	V	4	3128.499		0
3121.529	Co	1	3128.634		0
3121.714	Co,-	3	3128.819	Cr,-	2
3121.893		1	3128.889		00
3121.969		00	3129.010	Fe?	1
3122.079		00	3129.120	Co	000
3122.192		0	3129.220	Fe?	1
3122.329		0	3129.290	Zr	0
3122.427	Fe?	1	3129.433	Fe, Ni	3
3122.680		2	3129.645	Co,-	00 N
3122.774		00	3129.880 s	Zr	0
3122.894		0000	3130.060		00 N
3123.019		0	3130.250		00 N
3123.059		00	3130.380	V	3
3123.203	Ti	0	3130.529		1
3123.371		00	3130.681		1
3123.460	Fe?	0	3130.745	Be?	0
3123.554		00	3130.909	Ti,-	3
3123.672		1	3131.169	Be?	1 N
3123.809		0000	3131.350	Cr,-	0
3123.889	Ti?	00 N	3131.475		0
3124.070		1	3131.560		0
3124.208	Fe?	0	3131.640		0
3124.394		000 N	3131.822		0
3124.599		00	3131.920		000
3124.749		00	3132.065		000
3124.799		000	3132.169	-,Cr	4
3124.914		00	3132.303	-,Co	0
3125.029		2	3132.402	Mn?	0
3125.109	Cr,-	4	3132.635	Fe?	2
3125.164		2	3132.749	Mo	1
3125.399		5	3132.935	Cr,-	00 N
3125.579	Cr?	00	3133.180		1
3125.779	Fe, V	5	3133.330	Cd, Zr	1
3126.029	Zr	0	3133.449	V	2

RESEARCHES ON THE ARC SPECTRA OF THE METALS. II. THE SPECTRUM OF TITANIUM.[1]

By B. Hasselberg.

1. For some time past I have been engaged at the Physical Institute of this place in a systematic investigation of the arc spectra of the metals, and in recent publications of the Academy[2] I have described at some length the spectrum of chromium. The investigation includes that part of the spectrum which can be photographed with glass objectives, and which extends from λ 3450 to D. The following pages are devoted to a consideration of the same part of the spectrum of Titanium. But while chromium has only scattered unimportant lines in the less refrangible parts of the spectrum, titanium has a considerable number of very characteristic groups in the same region, and it would have been desirable to include these groups in the investigation, if such a course had been possible. As it was, the considerable difficulties which are still in the way of obtaining satisfactory photographs in this part of the spectrum, have induced me to forego this part of the investigation for the present, particularly since, on the one hand, the main requirements of astrophysics are satisfied by the part which is here considered, and, on the other hand, it is probable that the less refrangible rays can be photographed under considerably improved conditions in the immediate future.

2. Our present knowledge of the spectral relations of titanium rests almost exclusively on the investigations carried out by Thalén[3] nearly thirty years ago. At first, in these investigations, titanic acid was used, with which only a small number of excessively fine and inconstant lines could be observed in the spark

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[1] "Untersuchungen über die Spectra der Metalle im electrischen Flammenbogen, II., Spectrum des Titans." Translated from the *Kongl. Svenska Vetenskaps-Akademiens Handlingar*, **28**, No. 1, Stockholm, 1895.

[2] *Svenska Vetensk. Akad. Hand.*, **26**, No. 5, 1894.

[3] *Nova Acta Reg. Soc. Sc. Upsal.*, Ser. III., **6**, 1868.

spectrum and identified with solar lines. These lines were found later in the electric arc, when carbon points which had been saturated with calcium chloride were employed, and in order to determine their origin, the titanium spectrum was again produced, with the aid of titanium chloride. This spectrum proved to be free from calcium lines, and contained, among a great multitude of sharp lines, the lines which had formerly been observed, and which it was consequently necessary to ascribe to titanium. At the same time the result was established, that the presence in the calcium spectrum of the lines in question was due to titanium in the carbon points.

The number of lines observed by Thalén in this spectrum between λ4163 and λ6556 is about 200, of which the greater part occur as absorption lines in the solar spectrum. The conclusion that titanium exists in the atmosphere of the Sun is therefore perfectly well established, although the intensities of corresponding lines are not always the same; this relation is one that is constantly met with, even in the case of metals, which, like iron, have an undoubted part in the Sun's chemical constitution. It will moreover appear in the following pages that many lines which were noted as "broad" by Thalén, are really groups of two or more lines, each component having a corresponding line in the solar spectrum; thus, the existence of the metal in the Sun receives a still further confirmation.

3. Since, according to Thalén's experience, titanic acid in its ordinary form is unsuitable for producing the spectrum by means of the induction spark, it is probable that this will also be the case when the electric arc is employed. The use of salts is also objectionable in many respects, and at first, therefore, I tried to use the pure metal in the form of powder; but this method likewise proved to be impracticable, since, when the current was passed, the burning metal was scattered in all directions and the spectrum was quickly extinguished. Titanic acid was then obtained from Baron Nordenskiöld in the form of *rutile*, and with this mineral perfectly satisfactory results were obtained. A small piece introduced into the crater of the positive (lower) carbon,

immediately melts into a bead, above which the arc burns very quietly, giving a brilliant, steady and lasting spectrum. It is true that iron in considerable quantities is to be feared as an impurity, but so far as I have been able to observe, the material which I have used merely increases, by a scarcely perceptible amount, the number and intensity of the iron lines which are due to the carbon points, and which would be visible in any case.

4. After the production of a titanium spectrum which could be maintained for any desired length of time had been made possible, the photographic work could be taken up. With regard to the instrumental appliances and the photographic methods which were used, I have little of importance to add to the account given in my previous memoir. Everything remained as before except that, in some cases, Ilford color-sensitive plates were used instead of those of Lumière, for the reason that the last lot of Lumière plates was considerably inferior to the first with respect to fineness of grain. The Ilford plates were notably better in this respect, although they did not yield quite so brilliant negatives.

5. The photographs were measured in the same way as those of the chromium spectrum. First a provisional catalogue was made, containing all the lines to be measured, and by comparison with photographs of the iron spectrum taken at the same time, most of the iron lines in the titanium spectrum were at once excluded. The measurements were then carried out in two independent series, each on different plates, and the definitive wave-lengths were determined from them according to well-known methods. For measuring I used the same dividing engine by Perraux, as before; but since the old microscope belonging to it was in many respects not all that could be wished, it was replaced by a new one, furnished by Toepfer, of Potsdam, which had Zeiss lenses, and which proved to be entirely satisfactory. It is characterized by great sharpness and clearness of the image to the extreme edge of the very large field, so that my photographs, which even formerly appeared to

be good, now represented for the first time the high perfection of the spectra yielded by the Rowland grating. It frequently happened that a close double line was resolved by the new microscope, which appeared single under the old one. Further, the eyepiece can be accurately focused on the cross-wires by means of an oblique slot in its mounting, and the cross-wires can be rotated about the axis of the instrument, so as greatly to facilitate the adjustment of the wire to parallelism with the spectral lines. The magnifying power can be varied within the limits of 10 and 18 diameters.

In consequence of the greater sharpness of the image, the certainty of a setting on the spectral lines is perceptibly increased. It is therefore not improbable that two settings on each line would be a sufficient number in measuring each plate, instead of three as in earlier measures, and that the accuracy would not be sensibly diminished by the change. However, I have not made any change as yet, in order to preserve the homogeneity of the measurements.

6. Although a few words have sufficed for the points of the investigation hitherto touched upon, the question of the elimination of lines due to impurities requires a more detailed consideration. This is by far the most difficult part of the investigation, and no surprise need be felt if the desired end has been only approximately reached. Nevertheless, I entertain the hope that the impurities which remain are of only secondary importance.

The adopted method of elimination has already been described in connection with the spectrum of chromium. As soon as the wave-length catalogue of titanium was completed, it was compared line by line with the corresponding definitive or provisional catalogues of iron, cobalt, nickel, chromium and manganese. All pairs of lines in these metals and titanium which differed by less than 0.10 tenth-meter were carefully studied on plates containing both spectra which were prepared specially for the purpose, in order to obtain a definitive judgment as to their coincidence or non-coincidence, and, in the former case, to determine the probable origin of the foreign line from a consideration of the relative intensities. For calcium and other metals investigated by Kayser and Runge, I used the catalogues of these authors in the manner already described, but hitherto without a direct comparison of the spectra. I have then regarded the lines as follows:

A. As belonging to *titanium:*

a All lines which are distinctly separated from neighboring lines of the comparison metal.

b Those lines which coincide with lines of the comparison metal, but which have a much greater intensity in the titanium spectrum.

c Those lines which exactly coincide and are strong in both spectra, so that they must be regarded as belonging to both metals.

B. As *doubtful*, lines which perfectly coincide, but which are of feeble intensity in both spectra, and which may therefore be supposed to have their origin in a third substance existing as an impurity in the two metals compared.

C. As lines due to *impurities*, and therefore to be stricken from the titanium spectrum, such lines as are weak in the titanium spectrum and strong in that of the comparison metal, although coincident in both spectra.

Proceeding from these principles, I have arrived at the following results of the comparisons:

I. TITANIUM AND IRON.

As already mentioned, most of the iron lines, or at any rate all of the most conspicuous ones, were eliminated in the first review of the spectrum. A comparison which was made after the completion of the definitive catalogue with the iron spectrum of Kayser and Runge revealed a considerable number of cases in which lines of the two spectra had so nearly identical positions, that a new comparison on special plates containing both spectra seemed to be necessary. In order to make these and similar comparisons without an excessive amount of labor, a drawing of at least one of the spectra was necessary and for this purpose the originals of the accompanying plates were used. The results are given in the following table:

Ti		Fe		REMARKS
λ	i	λ	i	
3493.42	1.2	93.44	1	Fe missing.
3505.01	3	05.02	1.2	Coincident.
20.16	1.2	20.21	1	Fe missing.
24.37	2.3	24.41	1.2	Coincident.
26.18	1.2	26.15	1.2	Probably belongs to Fe, as the iron line on the comparison plate is strong.
30.53	3	30.55	1.2	Coincident. Impurity due to Ti in Fe, Ni, Co.
58.66	2	58.69	4	Coincident. The Ti line considerably stronger than other lines in the vicinity corresponding with strong iron lines.
78.84	2	78.87	1.2	Coincident. The lines in Ti spectrum are certainly Cr lines.
93.62	2	93.69	1	Fe missing.
96.18	2.3	96.10	1	Divided.
98.84	2.3	98.92	1	Divided.
99.25	2.3	99.19	1	Coincident? Fe line probably divided from Ti, Ni.
3603.98	1.2	04.05	1	Fe barely visible.
04.39	1.2	04.36	1	Fe missing.
06.16	1.2	06.12	1	Fe missing.
14.35	2	14.33	1	Divided. λ Fe < λ Ti.
19.61	1.2	19.61	1	Ni, Co has a strong line (5 and 4). To be stricken from Fe and Ti.
21.35	2	21.31	1	Divided. λ Fe < λ Ti.
24.96	2	25.02	1	Coinc.? Perhaps λ Fe > λ Ti. Probably we have 24.90 Ni—3 24.96 Ti—2 25.02 Fe—1
38.10	2	38.05	1	Divided; *i* for Fe > 1.
58.22	3.4	58.14	1	Divided.
69.08	2.3	69.11	1	Coincidence probable.
71.81	3	71.87	1	Divided. λ Fe > λ Ti. Fe line extremely faint.
77.89	1	77.83	2.3	Divided.
81.38	1.2	81.42	1	Divided. Ti appears to lie between two faint Fe lines.
83.19	1.2	83.25	1	Hard to see; probably divided, otherwise impurity due to Co.
90.03	3	90.05	1	Coincident.
3708.82	1.2	08.79	1	Both missing from comparison spectrum.
21.75	2	21.76	1.2	Divided; λ Ti > λ Fe.
59.42	3.4	59.37	1	Fe missing.
82.26	1.2	82.30	1	Too faint for observation.
3801.25	1.2	01.22	1.2	
06.19	1	06.19	1	
27.80	1.2	27.79	1.2	Possibly divided.
29.85	1.2	29.93	1.2	Both faint; suspected λ Fe > λ Ti.
46.56	2.3	46.62	1.2	Probably divided, but apparently λ Fe < λ Ti.
48.48	1.2	48.49	1	Probably divided; λ Fe < λ Ti.
55.99	1.2	56.07	1	Probably divided; λ Fe > λ Ti.
69.75	1.2	69.76	2.3	Coincident. Rather strong Fe lines in the vicinity missing from Ti spectrum.
74.32	2	74.25	1	Divided; λ Fe < λ Ti.
90.11	2	90.09	1	Divided; λ Fe < λ Ti; Fe weak.
3900.68	2.3	00.71	1.2	Coincident; *i* for Fe > 1.2.
58.33	3.4	58.36	1	Also in Ni. Impurity in Fe and Ni due to Ti.

Ti		Fe		REMARKS
λ	i	λ	i	
3981.92	3.4	81.94	3.4	Perfect coincidence; not divided.
98.77	4	98.83	1	Fe missing.
4009.05	3	09.04	1	Coinc.? Fe line much stronger than here indicated.
53.97	1.2	53.94	1	Perhaps divided, and λ Fe $<$ λ Ti.
55.19	2.3	55.19	1.2	Divided, but excessively close. Intensity of the Fe line 1.2.
59.07	2	59.06	1	Coincident. Fe stronger than given by K. and R. Also weak Ni line.
82.57	2.3	82.62	1.2	Coincident. Fe faint.
99.94	1.2	99.94	1.2	Fe missing.
4105.31	1.2	05.31	1.2	
09.92	1.2	09.95	4	Fe a little more refrangible than Ti.
11.91	2.3	11.92	1.2	Like the preceding.
29.30	1.2	29.35	1	?
34.60	1.2	34.57	1.2	Divided; λ Ti $<$ λ Fe.
43.99	2.3	44.03	5	Belongs to Fe.
61.67	1	61.64	1.2	Divided; λ Fe $<$ λ Ti.
63.80	2.3	63.81	1.2	Perhaps divided, and λ Fe $>$ λ Ti.
72.04	2	72.06	1	Coincident. Fe distinct but faint.
73.66	1.2	73.59	1	Fe distinct; divided from Ti; λ Fe $<$ λ Ti.
74.61	1.2	74.54	1	Fe missing.
86.27	3.4	86.27	1	
4265.42	1.2	65.44	1.2	Fe weak. Coinc.?
78.34	2	78.42	1.2	Trace of Fe; coinc.?
88.29	1.2	88.32	2.3	Complete coincidence.
90.07	1.2	90.11	1	Fe missing.
91.07	3	91.06	1	Perhaps divided, and λ Fe $<$ λ Ti.
95.91	3.4	95.90	1	Also in Co, therefore impurity in Co and Fe due to Ti. Fe absent
4301.23	3.4	01.23	1	
14.50	2.3	14.50	1	
18.83	3.4	18.85	1	K. and R. give for Ca 18.80.
25.30	3	25.26	1	
38.05	3	38.12	1	
46.76	1	46.73	2.3	Divided; λ Fe $<$ λ Ti. Intensity of Fe line $<$ 2.3.
67.81	1.2	67.75	1	Distinctly divided; λ Fe $<$ λ Ti. Intensity of the Fe line $>$ 1.
79.40	2	79.43	1.2	Fe missing; also a weak line in Co.
84.85	2	84.89	1.2	Probably divided; λ Fe $>$ λ Ti.
88.69	1	88.64	3.4	Distinctly divided; λ Fe $<$ λ Ti.
90.11	2	90.17	1.2	Fe missing.
4400.74	1.2	00.79	1	Fe line doubtful, on account of ghost of strong Fe line λ 4404.94.
07.83	1.2	07.87	3.4	Distinctly divided; λ Fe $>$ λ Ti. $\Delta\lambda > 0.04$.
08.70	1.2	08.61	3.4	Widely divided. Intensity of Fe line too great.
11.26	1	11.19	1	?
18.52	1.2	18.50	1	Fe missing.
26.24	2.3	26.15	1	
31.46	2	31.50	1	Fe weak; λ Fe $>$ λ Ti.
32.76	1.2	32.75	1.2	Fe visible; coinc.?
41.86	1.2	41.87	1	Fe missing.
62.26	1.2	62.18	2.3	Fe quite strong. Fully divided.

Ti		Fe		Remarks
λ	i	λ	i	
4463.70	2	63.73	1	Fe missing.
65.96	2.3	66.02	1	Fe distinct; possibly λ Fe < λ Ti. Also a line in Co. Both probably impurities due to Ti.
71.40	2.3	71.38	1	Fe missing.
75.00	2.3	74.94	1	Traces of Fe; suspected λ Fe < λ Ti.
79.86	2	79.80	1.2	Fe distinct; lines divided. λ Fe < λ Ti.
96.33	3	96.27	1.2	Fe weak; lines divided. λ Fe < λ Ti.
97.90	1.2	97.93	1	Fe missing.
4527.48	3	27.42	1	Traces of Fe; apparently λ Fe < λ Ti.
33.42	3.4	33.42	1	Fe distinct. Exact coincidence. The line coincides with a ghost of the strong Fe line 31.31, and like the corresponding line in Ni is an impurity due to Ti.
34.15	2.3	34.20	1	Co has 34.18 (4) and is probably divided from Ti. Fe missing. The lines in Fe and Ni are impurities due to Ti.
34.97	3.4	35.01	1	
35.75	3	35.72	1	
36.12	3	36.17	1	Fe missing.
36.25	3			
48.93	3.4	48.95	1	
58.28	1.2	58.25	1	Trace of Fe; coincidence?
94.28	1	94.32	1	Fe missing. Ti weak.
4629.47	2.3	29.51	1	Coinc.? Traces of Fe. The line in Fe belongs to Co.
40.60	1	40.51	1	Fe missing.
75.27	2.3	75.30	1	
4792.65	2.3	92.69	1	
4811.24	2	11.29	1	
44.13	1.2	44.20	1	Fe missing, or only as a trace.
48.62	2	48.64	1	Fe missing.
70.28	3	70.21	1	Trace of Fe; probably divided, and λ Fe < λ Ti.
4913.76	3	13.86	1	Fe missing.
48.40	1.2	48.45	1	
77.92	1.2	77.86	1	
5025.72	3	25.67	1	
87.24	2.3	87.23	1	
5103.39	1	03.44	1	Missing on several plates of both Ti and Fe.
73.94	3	73.92	1	Fe missing.
93.15	3	93.17	1	
94.26	1.2	94.27	1	
5201.32	1.2	01.29	1	
19.88	2	19.83	1	
24.46	2.3	24.47	1	
26.70	1.2	26.70	1	
84.61	1.2	84.70	1	
5409.81	2.3	09.82	1	
38.53	1.2	38.58	1	Fe missing. Ti weak.
72.90	1.2	72.95	1.2	Fe missing.
81.64	2.3	81.69	2.3	Traces of Fe. Coinc.? Mn has a strong line here.
5514.78	3	14.78	1	Fe missing.
5712.07	2	12.09	1.2	Traces of Fe. Coinc.? Line probably belongs to Ni and Ti.
15.30	2.3	15.31	2.3	Traces of Fe; perhaps λ Fe < λ Ti. Line probably belongs to Ti and Ni.
40.20	2	40.17	1	Fe missing.

It will be seen from this table, in which, to facilitate the comparisons, I have given the intensities of Kayser and Runge reduced to my own scale, that a considerable number of the faintest iron lines observed by these investigators were not found by me, and this was also the case in the spectrum of chromium. The explanation of this circumstance would seem to lie in the greater purity of the iron which I used, provided that the absence of the lines is not due to my possible use of two weak a current. In the latter case—if the lines appear with a stronger current and have exactly the same positions as the titanium lines,—they would generally (taking their intensities into account) have to be excluded from the spectrum of iron, as impurities due to the presence of titanium.

In the group *A, c* containing lines which belong to both metals, are to be placed the following lines.

λ	i	
	Ti	Fe
3558.66	2	4
3869.75	1.2	2.3
3981.92	3.4	3.4
4288.29	1.2	2.3
5481.64	2.3	2.3

The last of these lines is found in my spectrum of iron as a trace only. On the other hand manganese has a strong line here ($i = 3$), and for this reason the line observed by Kayser and Runge may be regarded as due to maganese existing in iron as an impurity.

In group *B* fall the following lines, which I provisionally ascribe to titanium, since it cannot be decided at present whether they belong to a third metal or not:

λ	i	
	Ti	Fe
3526.18	1.2	1.2
3708.82	1.2	1
3782.26	1.2	1
3801.25	1.2	1.2
3806.19	1	1
4109.92	1.2	4
4129.30	1.2	1
4265.42	1.2	1.2
4411.26	1	1
4433.76	1.2	1.2
4594.28	1	1
5103.39	1	1

The intensity of the line λ 4109.92 is certainly estimated too high by Kayser and Runge; I find it to be only 1.2.

As impurities only the following lines remain to be considered, after the exclusion of lines from the titanium spectrum on the first revision:

λ	i		
	Ti	Fe	
3578.84	2	1.2	Cr
3593.62	2	1	Cr
3619.61	1.2	1	Co, Ni
3683.20	1.2	1	Co
4143.99	2.3	5	

Of these lines only the last is an iron line. The others belong neither to titanium nor to iron, but to cobalt, nickel and chromium, and are therefore to be removed from the iron spectrum of Kayser and Runge, as impurities.

2. TITANIUM AND COBALT.

The result of the comparison was the following table of approximate coincidences:

Ti		Co		REMARKS
λ	i	λ	i	
3495.88	2	95.81	3.4	Divided; λ Ti > λ Co.
3530.53	3	30.52	1.2	Coincident.
42.69	1.2	42.73	1	Coincidence impossible to decide upon.
87.27	2	87.30	5	Coincident. To be stricken from the Ti spectrum.
99.25	2.3	99.27	2	Coincident.
3605.46	2	05.49	3	Coinc. The line in Ti spectrum belongs to Cr. The Co line must, however, be independent of Cr, since the two Cr lines at λ 3593.57 and λ 3578.81 are missing from the Co spectrum.
09.45	1.2	09.46	1.2	
13.89	2	13.90	1.2	Coinc. The Ti line variable.
19.61	1.2	19.54	4	Coinc. probable.
33.60	2	33.51	1.2	Widely separated.
62.37	2.2	62.33	3	Divided; λ Ti > λ Co.
83.20	1.2	83.18	3.4	Variable in Ti.
3702.42	2	02.40	2.3	Divided; λ Ti > λ Co.
07.68	1.2	07.61	2	Widely separated.
3860.61	1.2	60.56	2	Probably divided.
61.25	1.2	61.30	3	Divided; λ Co > λ Ti.
90.12	1.2	90.16	1.2	Coinc.? Perhaps λ Co > λ Ti.
98.68	2	98.64	2	Co line doubtful.
3904.95	3.4	04.93	1.2	Coinc.
36.11	1	36.12	4	Coinc. To be stricken from the Ti spectrum.
4109.92	1.2	09.83	1.2	Co barely visible; probably belongs to Fe.
4287.55	3.4	87.51	2	Coincidence apparently exact.
4301.23	3.4	01.22	1.2	Exactly coincident. Co line weak. Also in Fe (1).
75.61	1.2	75.70	2.3	Widely separated.
79.40	2	79.37	1.2	Divided. Also in Fe.
95.99	1.2	95.99	2	Divided, but slightly.
4416.70	2	16.63	1.2	Distinctly separated.
17.88	2.3	17.88	1	Co line barely visible.
62.26	1.2	62.17	1.2	Widely separated. The line in Co belongs to Fe.
65.96	2.3	65.95	1.2	Co line variable. Also a weak line in Fe.
4534.15	2.3	34.18	4	Probably divided.
49.79	3	49.80	4	Divided, but excessively close.
52.62	3.4	52.60	2	Coincidence exact; *i* for Co appears to be variable.
4623.24	3	23.15	2.3	Widely separated.
29.47	2.3	29.47	4.5	Coincidence apparently exact; possibly λ Ti < λ Co.
45.36	2.3	45.34	1.2	Co line variable.
97.10	2	97.19	1.2	Widely divided.
4766.48	2	66.57	2	Widely separated.
71.26	1.2	71.27	3.4	Exactly coincident.
78.44	2.3	78.42	2.3	Perhaps divided; λ Ti > λ Co.
80.15	1.2	80.14	4	Coinc.
4928.50	2.3	28.48	3	Absolute coincidence.
81.92	4	81.91	1	Co extremely faint. To be stricken from the Co spectrum.
5001.16	2.3	01.15	1	Co missing.
07.42	4	07.48	1.2	Divided; λ Co > λ Ti.
13.45	3	13.46	1	Co missing.
5283.63	2.3	83.68	1.2	Probably divided; λ Ti < λ Co.
5369.81	2.3	69.78	3	Coincident; *i* variable in Ti spectrum.
5488.44	2.3	88.37	1.2	Divided; λ Co < λ Ti.

It will be seen that in most of these pairs the lines are independent of each other. I believe that the following lines may with some probability be regarded as belonging to both metals:

λ	i	
	Ti	Co
4629.47	2.3	4.5
4928.50	2.3	3
5369.81	2.3	3

Of these lines the first is (according to Rowland also, who gives the wave-length 4629.51), to be ascribed to both titanium and cobalt. The lines which I regard as doubtful are:

λ	i	
	Ti	Co
3609.45	1.2	1.2
3613.89	2	1.2

On the other hand the following lines are to be removed from the titanium spectrum, as impurities due to cobalt:

λ	i	
	Ti	Co
3587.27	2	5
3619.61	1.2	4
3683.20	1.2	3.4
3936.11	1	4
4771.26	1.2	3.4
4780.15	1.2	4

The line λ 3683.20 is ascribed by Rowland (with wave-length 3683.21) to iron and vanadium as well as to cobalt.

3. TITANIUM AND NICKEL.

The following table contains the results of the comparisons of these two spectra:

Ti		Ni		Remarks
λ	i	λ	i	
3495.88	2	95.80	1	The line in Ni is the Co line 95.81 (3.4); divided from Ti.
3530.53	3	30.45	2	Coinc. Co has a line at 30.52 (1.2). Probably belongs to Ti.
87.27	2	87.35	1.2	The line in Ni belongs to Co (87.30, $i = 5$). To be stricken from Ti.
99.25	2.3	99.25	2	Coincident.
3609.45	1.2	09.45	2.3	Ti line variable. Extremely faint on comparison plate; therefore to be stricken out.
13.89	2	13.90	1.2	The Ni line probably a ghost, and therefore to be stricken out.
19.61	1.2	19.60	5	Probable coincidence either with Ni or with Co 19.54. To be stricken from the Ti spectrum.
24.97	2	24.90	3	Widely separated; λ Ti > λ Ni.
36.05	1	35.95	1.2	Ni missing from comparison plate.
97.05	1	97.00	1	Coincident.
3722.70	2.3	22.70	3	Perhaps slightly divided, in sense λ Ti > λ Ni.
3811.56	1.2	11.45	1	Widely separated; λ Ti > λ Ni.
61.25	2	61.30	1	Divided; λ Ti < λ Ni.
3936.11	1	36.10	2.3	To be stricken from Ti; probably belongs to Co.
58.33	3.4	58.35	1	Exact coincidence. These lines are probably to be stricken from the Ni spectrum. The line 81.91 belongs to Ti and Fe.
81.91	3.4	81.95	1	
89.92	4	89.90	1	
98.77	4	98.75	1.2	
4025.26	1	25.25	1.2	Ni line so faint that coincidence could not be decided upon.
58.28	2	58.35	1	Like the above.
59.07	2	59.05	1	Like the above.
64.36	2	64.45	2	Widely divided.
4164.80	1	64.85	1	Coinc. Common impurity?
4318.83	3.4	18.85	1	Ni missing; K. and R. give for Ca 18.80.
30.85	1.2	30.84	2	Perhaps divided.
41.51	1.2	41.57	1	Ni missing.
4455.48	3	55.50	1	Ni missing.
63.70	2	63.60	2	Widely separated. The Ni line lies between Ti 63.70 and 63.52 and is divided from both.
80.72	2	80.80	2	Coinc. Ni weak on comparison plate.
81.41	2.3	81.35	1	Ni missing.
4506.51	1.2	06.50	1	Ni missing.
33.42	3.4	33.40	1	Ni missing. K. and R. have for Fe 33.42, weak. Ti line certain.
34.15	2.3	34.20	1	The line in Ni spectrum belongs to Co, and is probably divided from Ti.
34.97	3.4	35.00	1	Ni missing from comparison plate.
49.79	3	49.85	1	The line in Ni spectrum belongs to Co, and is divided from Ti.
60.08	2	60.10	2	Coinc. Ni line variable.
4629.47	2.3	29.50	1	The line in Ni spectrum belongs to Co.
55.82	2	55.87	1.2	Division uncertain; common impurity?
4799.95	2.3	4800.00	1	Coinc.
4864.37	1.2	64.46	1	Divided; λ Ti < λ Ni.
5014.40	4	14.40	1	Coinc.
5397.28	2	97.30	1	Divided; λ Ti < λ Ni.
5712.07	2	12.05	3	Coinc.
15.30	2.3	15.30	3	Perhaps slightly divided.

Only the following four lines are to be regarded as belonging to group *A, c:*

λ	i	
	Ti	Ni
3599.25	2.3	2
3722.70	2.3	3
5712.07	2	3
5715.30	2.3	3

The first of these also occurs in the spectrum of cobalt. Rowland makes the wave-length of the second line 3722.71, and attributes the line partly to nickel and partly to titanium and iron.

As impurities of titanium I have had to strike out only the two lines:

λ	i	
	Ti	Ni
3609.45	1.2	2.3
3619.61	1.2	5

of which the last is also a very strong line in the spectrum of cobalt, while the first is a weak line in this spectrum and must therefore be attributed to nickel. The following lines therefore remain as doubtful:

λ	i	
	Ti	Ni
3697.05	1	1
4025.26	1	1.2
4164.80	1	1
4330.85	1.2	2
4480.72	2	2
4560.08	2	2
4655.82	2	1.2

4. TITANIUM AND MANGANESE.

Manganese furnishes, as the following table shows, only a small number of approximate coincidences with titanium:

Ti		Mn		**Remarks**
λ	i	λ	i	
3599.25	2.3	99.25	1	Perhaps divided. The intensity of the Ti line too great.
3601.31	1	01.40	1	Divided; λ Ti < λ Mn. Hard to see.
41.48	2.3	41.55	1	Widely separated.
85.30	4	85.25	1	Coinc. To be stricken from Mn.
3741.19	3	41.15	1	Coinc. Belongs to Ti. The Mn line has variable intensity on different plates.
3829.81	1 +	29.83	2.3	Appear to be divided; but λ Ti > λ Mn.
34.06	1.2	34.00	3.4	Probably divided, and λ Ti > λ Mn.
60.61	1.2	60.55	1	Mn missing from comparison plate.
61.89	1.2	61.85	1.2	Probably divided.
3904.95	3.4	04.90	1 +	Perhaps divided.
26.48	2 +	26.55	2.3	Widely divided; λ Ti < λ Mn. Δ λ > 0.07.
82.62	2.3	82.70	2	Widely divided.
4059.07	2 −	59.05	3.4	Cannot be divided. The Ti line is perhaps an impurity.
65.23	2	65.20	2	Perhaps divided, and λ Ti > λ Mn.
90.73	1	90.75	1 +	Both lines missing from comparison plate.
4123.42	1.2	23.40	1.2	Coincident.
23.68	2.3	23.65	1.2	Probably divided, and λ Ti > λ Mn.
28.20	1.2	28.25	1	Mn missing.
31.38	1.2	31.30	2.3	Widely separated.
37.39	2 +	37.40	1.2	Coincident.
66.45	2 −	66.35	1	Mn missing.
4211.85	1.2	11.95	2	Divided; λ Ti < λ Mn. Δ λ < 0.10.
4388.22	1.2	88.22	1	Coincident.
4455.48	3	55.50	3	Coincidence apparently exact.
57.59	3.4	57.70	3	Widely separated; λ Ti < λ Mn.
62.26	1.2	62.20	4	Divided; λ Ti > λ Mn.
4766.48	1.2	66.55	3.4	Fully separated.
5481.64	2.3	81.60	3	

As common to both metals are to be regarded the lines λ 4455.48 and λ 5481.64 only. The line λ 4059.07 probably belongs to manganese and not to titanium. The following lines are still doubtful:

λ	i	
	Ti	Mn
4123.42	1.2	1.2
4137.39	2	1.2
4388.22	1.2	1

5. TITANIUM AND CHROMIUM.

These two spectra had already been compared in connection with the investigation of the spectrum of chromium. Most of the approximate coincidences which were found in the first revision proved to be merely apparent, since a separation of the lines was effected in all but a comparatively few cases. Of these lines the following are to be regarded as common to both spectra:

λ	i	
	Ti	Cr
3558.66	2	2.3
4122.31	2	2
4295.91	3.4	2.3
5225.15	2.3	3

The following lines are possibly due to a third metal existing as an impurity in both titanium and chromium:

λ	i	
	Ti	Cr
3556.32	1.2	1
3696.00	1	1
3786.44	1.2	1
3836.22	1	2
4261.75	2	1.2

6. TITANIUM AND CALCIUM.

Of the spectral lines of calcium only a few of the most intense are found here and there on my plates. Their differentiation from the titanium lines is in general not a difficult matter, since they usually appear as pointed lines only in the neighborhood of the carbon points. Most of them could therefore be eliminated with the iron lines in the first review of the spectrum. A comparison with Kayser and Runge's wave-length catalogue of calcium lines gave only the following coincidences:

Ti		Ca	
λ	i	λ	i
3653.61	5	53.62	3
4318.83	3.4	18.80	5
4355.44	1	55.41	4

In this, as in other tables, I have reduced the estimates of the intensity of the calcium lines to my own scale. The last of these lines is perhaps to be removed from the titanium spectrum as an impurity due to calcium; the others are apparently to be ascribed to both metals. Kayser and Runge have also observed the first line in the spectrum of strontium, although they attribute it to calcium.[1] Rowland likewise attributes the line λ 4318.83 to calcium,[2] and gives its wave-length as 4318.82.

7. TITANIUM AND STRONTIUM.

In the wave-length table for strontium given by Kayser and Runge, are the following lines, which have nearly identical positions with lines in the titanium spectrum:

Ti		Sr	
λ	i	λ	i
3477.33[3]	2.3	77.33	2
4338.05	3	38.00	4
5238.77	2	38.76	6

The last line is one of the strongest in the strontium spectrum. The coincidence with the titanium line is quite certainly only an accidental one, as with titanium there is no trace of the other principal lines of strontium, like those at λ 5156.37, 5257.12, 5404.48, and 5481.15. So in the cases of the other two lines, which are sharp in titanium, but diffuse and even unsymmetrically defined in strontium, the coincidence must certainly be merely accidental.

8. TITANIUM AND BARIUM.

The approximate coincidences of lines in these spectra, which I have found with the aid of Kayser and Runge's observations, are as follows:

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[1] *Spectren der Elemente*, Abth. IV. 31.

[2] *A. and A.*, 1892, p. 231.

[3] 3467.33 in the original, by an obvious misprint.—*Ed.*

Ti		Ba		REMARKS	
λ	i	λ	i		
3525.28	1.2	25.23	4	± 0.10	Diffuse; reversed.
3593.61	2	93.58	3	.15	Diff. toward red.
3861.89	2	61.87	2	.10	Diffuse.
4291.32	2	91.32	3	.05	
4325.30	3	25.38	2	.05	
4489.24	2.3	89.50	3	.50	Diff. toward violet
4900.08	3	00.13	5	.05	
5381.20	1.2	81.25	1	.50	Diff. toward red.

Of these coincidences, the second, sixth and last may be at once regarded as accidental, both on account of the great uncertainty in the wave-lengths of the barium lines, and their unsymmetrical diffuseness. According to Rowland, the barium line λ 4900.13 falls between the titanium line (λ = 00.10, Rowland) and a line of yttrium at λ 4900.31, and is therefore independent of both. The three lines λ 3861.89, 4291.32 and 4325.30 appear to have the same character in both metals, and may, on account of their nearly identical intensity, if the coincidence is exact, be common to both. Only in the case of the first line is the existence of an impurity due to barium to be considered; but since none of the other principal lines of barium can be found in the titanium spectrum, and taking into account the considerable uncertainty in the position of the barium line, the coincidence may probably be regarded at only an apparent one

9. COMPARISON OF TITANIUM WITH THE REMAINING METALS HITHERTO INVESTIGATED BY KAYSER AND RUNGE.

The immediate result of this comparison was, that not a single coincidence with titanium is found in the metals magnesium, zinc, mercury, aluminium, thallium, lead, antimony, sodium, potassium and cæsium. On the other hand, a few approximate coincidences with titanium lines are found in the spectra of lithium, rubidium, indium, tin, bismuth and cadmium, which, if they are exact, demonstrate nothing more than this fact, which is repeatedly met with in the preceding comparisons, that two metals may accidentally emit identical radiations; for, since most of the principal lines of the comparison metals are completely lacking in the titanium spectrum, it is extremely improbable that the lines in question are due to the presence of these metals as impurities. The coincident lines are given in the following table, together with the limits of error in their wave-lengths which are assumed as possible by Kayser and Runge:

λ	i	λ	i	REMARKS	
4273.45	1.2	73.44	3	± 0.20; diff. toward red	Li
3587.27	2	87.23	4	.05; reversed.	Rb
4511.32	1.2	11.44		.10; reversed	In
3801.25	1	01.16	4	.05	Sn
3981.91	3.4	81.92	2	diff. toward red	Cd
5298.61	2	98.52	2	.20; diff. toward red	Bi
4492.70	1.2	92.79	3	.03	Bi
3596.17	2.3	96.26	3	.03	Bi
3510.98	3	11.00	3	.03	Bi

(*To be continued.*)

MINOR CONTRIBUTIONS AND NOTES.

NOTICE.

THE attention of subscribers is called to the fact that THE ASTROPHYSICAL JOURNAL is not issued in September. The next number will be published in October.

NORMAL SPECTRUM OF THE ZINC ARC.

A PHOTOGRAPHIC map of the arc spectrum of Zinc has recently been prepared by Professor Crew, by the use of metallic electrodes in motion. (*Philosophical Magazine*, October 1894.)

The main purpose of the map is to show the physical character of the Zinc lines which Ames, Kayser and Runge have measured and studied in such a masterly manner. (*Wied. Ann.* Bd. 43 pp. 385–409.)

The part of the spectrum mapped includes the region between w.l. 6500 and w.l. 2100. The photographs are made with a Rowland grating of 14438 lines to the inch and 10 feet radius. The series includes eight plates, on each of which, in addition to the Zinc spectrum, is photographed the arc spectrum of Iron, and a scale of single Ångström units, seventy to the inch. The figures are put on this scale by the hot needle method devised by Mr. O. H. Basquin (ASTROPHYSICAL JOURNAL, February 1895.) The scale will be found to be correct to within a fraction of an Ångström unit; more accurate readings, if desired, can be made by interpolation in the Iron spectrum which is practically not displaced at all with reference to the Zinc.

On the back of each plate is printed a table of wave-lengths for the Zinc lines. The wave-lengths of most of the impurity lines are also tabulated and identified.

The metal used in the arc is the ordinary "chemically pure" zinc of commerce.

With two exceptions the entire series lies in the spectrum of the second order, each plate covering 800 Ångström units and overlapping the preceding plate by half its length, so that each region of the spectrum appears on two different plates. Since it is manifestly impossible to give each line its proper exposure, the preference has generally been shown to the weaker lines, with the result that all of Kayser and Runge's lines with perhaps two exceptions may be seen on the original negatives, while all but perhaps five of them may be seen on the silver prints. Naturally the impurity lines are very weak, and many that appear on the negative cannot be seen on the print.

The following details will perhaps indicate what has determined the exposure in each case.

LIST OF PLATES.

No. of Plate	Region of Spectrum	Remarks
1.	6500. to 5200.	First order. Shows the very intense and characteristic red line of the spark and flame spectra at w.l. 6362.5; photographed in the arc by Rowland, not given by Kayser and Runge. The great density of the photograph near w.l. 5600 is not due to real intensity of the spectrum in this region, but to the special sensitiveness of an orthochromatic plate for rays of a corresponding wave-length.
2.	5700. to 4900.	Shows the line of longest wave-length measured by Kayser and Runge, *viz.*, w. l. 5182.20.
3.	5300. to 4500.	Shows the extraordinary intensity of the blue triplet as compared with all its neighbors. The "ghosts," which are almost invariably produced by a diffraction grating, but which are generally so faint that they do not show on photographs, are in this case quite conspicuous.
4.	4900. to 4100.	Shows the reversal of the blue triplet, the homologue of the green triplet of Magnesium.
5.	4500. to 3700.	Shows incidentally the care necessary in the identification of lines, since here the *impurity* lines in "chemically pure" Zinc far outstrip the Zinc lines in both number and intensity.
6.	4100. to 3300.	A region practically barren of Zinc lines, and one which may, therefore, be useful in mapping the spectra of non-conductors in cored Zinc electrodes, especially as this region is largely filled with Cyanogen lines.
7.	3700. to 2900.	Shows the first triplet (hitherto observed) of the "*erste Nebenserie*" of Kayser and Runge, together with two highly characteristic companion lines, all five strikingly reversed.
8.	3600. to 2100.	First order. Illustrates the crowding together of homologous groups at the ultra-violet end, a fact which has been used to explain a similar distribution of lines in the solar spectrum. Shows also w. l. 2138, the most characteristic single line in the whole spectrum of Zinc, the homologue of Mg 2852, which is, correspondingly, the most characteristic single line in the whole spectrum of Magnesium.

These silver prints are each mounted on white cardboard 2½ x 12 inches.

The set of eight photographs will be sent, postpaid, to any address for three dollars.

All orders and remittances should be sent to Business Agent Northwestern University, Evanston, Illinois, U. S. A.

The spectrum of the Magnesium arc, similar to the above in style, is also sold at three dollars.

The spectrum of the Aluminum arc will be published shortly.

July 1896.

THE DETECTION OF THE LINES OF WATER VAPOR IN THE SPECTRUM OF A PLANET.

THE recent discussion in this journal of the best form of instrument for observing the lines of water vapor in the spectrum of Mars leads me to describe some observations of my own, which seem to have a direct bearing on the question.

In the early part of 1895 I had been photographing the lower spectrum of Jupiter with an instrument of considerable power; namely, with the prism train of the Allegheny spectroscope, described in *Astronomy and Astrophysics*, 12. The distance between the *b* and D lines on the plate was about one inch, and the definition of the photographs was excellent. The spectrum of the planet extended to some distance below D, and therefore included the region of the principal band δ of aqueous vapor.

On these plates the spectrum of the planet seemed to be identical with the sky spectrum, which was photographed close beside it either on the day preceding or the day following the exposure. This result, though it agreed with Vogel's visual observations of the same part of the spectrum, induced me to make some experiments on the relative values of high and low dispersion for detecting the presence of water vapor lines. On March 3, when the sky was clear, I photographed the solar spectrum at intervals with the large spectroscope, until the Sun was near the western horizon, and at the same time observed the spectrum visually with a small direct-vision spectroscope. A comparison of the results showed that at low altitudes of the Sun the telluric bands near and above D were exceedingly strong in the small instrument and were by no means conspicuous on the photographs, where they were (partially, at least) resolved into separate fine lines.

ment. If the distinction between real and suspected variability is not maintained, the person first stating that all stars are variable might claim the discovery of all variables subsequently found. It will be seen that this star stands on a wholly different basis from the preceding star, since in that case the variability suspected by Thome was the reason for the further examination of this object. This star is $-22°$ 2739 in the *Bonn Southern Durchmusterung*. Its spectrum was found to be of the fourth type by Dunér.

The fifth star, R. A. $11^h 15^m 1^s$, Dec. $-61° 11'.4$ (1875), has maxima represented by the formula J. D. 2,411,100 + 162 E. The next maximum will accordingly occur on October 21, 1896.

The sixth star, — 19° 4047, ι Libræ, appears in four of the catalogues of stars measured with the meridian photometer. In Vol. XIV. measures on seven nights gave the magnitude 4.87. In Vol. XXIV., Table I., three nights gave the magnitude 4.36. In Vol. XXIV., Table IV., three nights gave the magnitude 5.02, and in Vol. XLIV., unpublished, three nights gave the magnitude 4.37. The discordance is so great as compared with that of other stars contained in these catalogues that variability of the star seemed to the writer the only reasonable explanation. Accordingly, visual observations were at once undertaken with the meridian photometer, and also by Argelander's method. By the latter method, Mr. Wendell soon confirmed its variability, finding it two grades fainter than θ Libræ on May 19, and two grades brighter than the same star on June 1, 1896.

The eighth star, $-37°$ 12782, has an approximate period of 136 days.

The ninth star, $-33°$ 14076, is a very remarkable object. It was one of a list of forty-two stars suspected of variability sent here for examination by Colonel E. E. Markwick of Gibraltar. A report was sent to him that an examination of several photographs failed to show any sign of variability. A few days later an object having a peculiar spectrum was discovered by Mrs. Fleming. All the plates of the region were examined and its variability established. It was about to be published in *Circular* No. 6 when it was found to be identical with the star of Colonel Markwick. It was accordingly reported to him for announcement, but he has kindly authorized its publication here. The photographs show that on eight nights in the summer of 1889, on six nights in 1890, on six nights in 1891, on five nights in 1892, on twelve nights during April, May, June, and July of 1893 the variation of light of this star was comparatively small and irregular. Colonel Markwick's first two observations on July 14 and 19, 1893 showed it of the seventh magnitude and a little brighter than the adjacent star —33° 14068. In August he found it fainter than this star, and by September 12 it was invisible and below the ninth magnitude. A photograph taken here on September 11, showed that it must then have been fainter than the magnitude 9.6, and on October 23, fainter than 11.3. Photographs taken on April 30, May 30, July 8, August 7, August 10, September 12, September 15, November 12, and November 13, 1894, gave the magnitudes 10.9, 10.3, 9.4, 8.6, 8.3, 7.5, 7.6, 6.4 and 6.4 respectively, thus showing a nearly regular increase in its normal brightness which it retained with irregular variations on twenty-seven nights in 1895. Observations by Colonel Markwick, beginning on August 20, 1894, lead to a similar result. The spectrum of this star is peculiar, and contains bright lines which show evidence of change.

The variation of the tenth star, —30° 19448, is small and irregular.

The spectra of the first, fifth, eighth, and probably the tenth stars are of the third type, having also the hydrogen lines bright. The second and seventh have spectra of the fourth type. These six variables were found by Mrs. Fleming in her regular examination of the Draper Memorial photographs.

MISCELLANEOUS NOTES.

A large number of observations has been made with the meridian photometer to determine the forms of light curve of stars of the Algol type. S Antliæ has hitherto been regarded as belonging to this class and is of interest from the shortness of its period, $7^h\ 46^m.8$, and since it was said to retain its full brightness for less than half of the time. It is difficult to reconcile the last condition with the theory that the variation is due to a dark eclipsing body. One hundred and seventy-seven measures, each containing sixteen photometric settings on S Antliæ, were made with the meridian photometer and give eight normal points. A smooth curve with only two points of inflection can be drawn through these normal points, the greatest deviation being 0.02 magnitudes. From this it appears that S Antliæ is not a star of the Algol type, that its light is continually changing, and that it belongs to the class of variables of short period like δ Cephei and η

Aquilæ. An interesting feature of this curve is that the time of increase occupies 0.62 of the entire time of variation, the increase of light being slower than the diminution.

U Pegasi appears to be second in this respect; since, according to the *Astronomical Journal*, 16, 108, its time of increase is 0.55 of the entire time, and that of other short period variables varies from 0.20 to 0.33. On the other hand, the time of increase is about 0.17 for No. 18 of the variables discovered in the cluster Messier 5 (see *A. N.*, 140, 285).

The star β Lyræ is commonly regarded as a variable of short period of the same class as the above. Observations of its spectrum, however, show that two or more bodies, revolving round each other, are present. The light curve found by Argelander may be closely represented by assuming that the primary minimum is caused by the eclipse of the brighter body by the fainter, and the secondary minimum by a similar eclipse of the fainter body by the brighter. This star should, therefore, be taken from the class of ordinary short period variables and included among the stars of the Algol type.

Mr. Backhouse calls attention to his announcement in the *Observatory*, 17, 402 of the variability of +0°939, announced in the ASTROPHYSICAL JOURNAL, 2, 198, and to his observations which indicate a period of not more than a year. Variability also suspected by Espin.

The variable star, R Microscopii, is identical with —29°17235.

EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY, CIRCULAR No. 9.

STARS HAVING PECULIAR SPECTRA.

A LIST of stars having peculiar spectra is given in the annexed table. They were all discovered by Mrs. Fleming in her regular examination of the Draper Memorial photographs. The number of stars of the third type is so large, now amounting to several thousands, that it has not been thought worth while to announce them, but to reserve them for a full list of stars having peculiar spectra to be published in a volume of the *Annals*. In the following table, the designation of the star in the *Durchmusterung* catalogues is given in the first column when it occurs in that work. The approximate right ascension and declination for 1900 are given in the next two columns, followed by the *Durchmusterung* magnitude. The fifth column gives the character of the spectrum, followed by additional remarks when required.

Designation	R. A. 1900	Dec. 1900	D.M. Mag.	Description
— 8° 1099	$5^h\ 17^m.6$	— 8° 45′	7.0	Peculiar.
......	7 38 .3	—70 7	....	Peculiar.
......	10 52 .0	—59 51	....	Peculiar. Resembles η Carinæ.
—37 7905	12 24 .0	—37 42	8.8	Type IV.
—34 11675	17 18 .5	—34 6	10.	Type V. { Gal. long. 320° 56′, lat. — 0° 30′
—39 12196	17 58 .2	—39 20	9.0	Type IV.
......	18 17 .5	—13 46	....	Type V. { Gal. long. 345° 14′, lat. — 1° 34′.
......	18 22 .2	—16 53	....	Type V. { Gal. long. 343° 2′, lat. — 4° 04′.
—25 13170	18 23 .2	—25 19	7.6	*Hβ* bright.
—38 12843	18 23 .4	—38 29	9.5	Type IV.
—31 15954	18 40 .0	—31 28	9.2	Peculiar.
—29 15574	18 52 .4	—29 38	8.9	Peculiar.
—40 13448	19 37 .1	—40 40	9.0	Peculiar. Resembles η Carinæ.
—18 5480	19 40 .6	—18 24	9.1	Type IV.
+85 332	19 43 .8	+85 9	9.2	Type IV.
......	20 15 .6	+16 25	....	Gaseous Nebula. { Gal. long. 26° 13′, lat. — 12° 09′.
— 12 5755	20 26 .2	—12 13	9.2	Type IV.
+ 5 5223	23 44 .0	+ 5 50	8.7	Type IV.

Of the seven stars whose spectra are here announced as of Type IV., the first, second and seventh are normal. The spectra of the others contain rays of much shorter wave-length than ordinary fourth type stars. The spectra of two faint objects announced as peculiar in the *A. N.* 135, 195, have been shown by recent and better photographs to belong to a different class from that there given. One of these, whose approximate position for 1900 is R. A. $17^h\ 38^m.2$, Dec. — 46° 3′, announced as a stellar object having the spectrum of a gaseous nebula, proves to have a faint continuous spectrum in which the hydrogen lines *Hβ*, *Hγ*, *Hδ*, *Hε*, and *Hζ* are bright, and the bright line at 5007 is absent, so that it more nearly resembles the spectrum of η Carinæ. The second object, — 33° 13537, R. A. $18^h\ 39^m.3$, Dec. — 33° 27′ (1900), announced as of the fifth type, proves to have the spectrum of a gaseous nebula.

EDWARD C. PICKERING.

July 9, 1896.

ON A NEW METHOD OF PREPARING PLATES SENSITIVE TO THE ULTRA-VIOLET RAYS.[1]

VI. THE DEVELOPMENT.

THE development is carried out solely with pyro and soda prepared according to Dr. Eder's formula (vide *Photographie mit Bromsilber-gelatine und Chlorsilber-gelatine*, 4th edition, 1890, p. 294).

I.	Crystallized sodium sulphite	100 grams
	Pyrogallic acid	14 "
	Sulphuric acid (to neutralize the alkaline sulphite)	6 drops
	Water distilled	500^{cc}

The sulphite is dissolved in the water, the acid added and finally the pyro.

II.	*Crystallized* sodium carbonate	50 grams
	Water distilled	500^{cc}

If anhydrous carbonate be used only half the above will be required.

The developer should only be used greatly diluted; otherwise spots and fog appear on the plates. I use for each volume of pyro and soda solution 3 to 6 volumes of ordinary water and some potassium bromide. The image appears in about 20 to 30 seconds, and is finished in two to three minutes. If the development is carried on longer fog comes on, notwithstanding the dilution of the developer, and sometimes even earlier. If the image is to show clear glass then the plate must be washed as soon as the fogging begins and fixed immediately afterwards. In my experiments the fogging frequently began after the development had gone on for 90 to 100 seconds. If the negative does not come up completely in this time another plate must be taken with longer exposure. There is no use in trying to attain the object by forced development.

It is only by observing this precaution that a clear picture can be obtained with these plates which are sensitive to the ultra-violet.

For spectrum photographs, which particularly require delicate delineation, especially for bringing out closely crowded lines, I have lately followed another method of developing. I take no heed of what appears on the plate—it would, in fact, soon be impossible, because the lines could not be seen in the development on account of their exceeding fineness; so I leave the plate in the developer for a certain time which I have ascertained by experience. It is true, I do not succeed with a single trial. As a rule the first negative I take in this way does not suffice, because the lines are too broad, and lines lying together are either massed together or insufficiently separated. In such cases I take another negative. Although I keep to the original exposure I shorten the development by some seconds. In this way I frequently obtain, but only after the third or fourth exposure, line pictures of a fineness which I cannot obtain with ordinary development. This mode of procedure takes up a good deal of time, but the beauty of the resulting negatives richly repays the great expenditure of time and trouble.

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[1] Continued from 3, 394.

The fogging of the plate can be restrained with potassium bromide, but care is necessary with it. *Potassium bromide exerts a decided influence on the size of the silver particles which form the negative or the so-called "grain" of the plate.* I take 5 to 10 drops of 10 per cent. solution of potassium bromide for 60 to 180^{cc} water, 20^{cc} pyrogallic acid and 20^{cc} soda solution.

With gelatine emulsions, it is assumed that the grain of the emulsion is of the same size as the grain of the image. If this is not strictly the case with such plates, as is shown by the microscope, it is still less so with plates sensitive to the ultra-violet rays.

The negative grain of a plate sensitive to the ultra-violet is in most cases a combination of several, often even of a great many grains of emulsion which together form a blackish-brown cluster of varying form and size. The size of this cluster depends on the nature of the sensitive coating and on the composition of the developer. It will be increased by silver iodide, but still more by potassium bromide in the developer. In general, silver bromo-iodide in a developer containing potassium bromide gives a coarser negative grain, while silver bromide in a developer free from bromide gives a finer one.

How much the size of the grain sometimes depends on the potassium bromide is shown by the following example. I cut a bromo-iodide plate into three parts and, without exposing to light before doing so, developed the first part without bromide, the second with a small addition of potassium bromide, the last with five times as much, and each until a strong fog appeared. The three plates show on a transparent ground a series of negative grains in turn 0^{mm}.02, 0^{mm}.14, and 0^{mm}.27 in size, besides it is true, many smaller grains also. All these grains have the form of a disk, and the distance between them increases with their diameter. These plates, especially the coarse-grained ones, quite produce the impression that the silver bromide, which at first covered the ground of the plate, had been used up in forming the larger clusters. Whether, and to what extent, the solubility of the silver bromide in potassium bromide is connected with the enlargement of the grain I must leave undecided, because I have not occupied myself further with this question.

The gelatine appears to have some influence on the formation of the usually angular or round-shaped negative grain. Silver bromide containing agar-agar gave me coarse moss-shaped forms.

The size of the negative grain of a bromo-iodide plate developed with a developer containing potassium bromide depends further on the nature of the cause which brings about the decomposition of the developable silver haloid. An unexposed plate developed to the point of fogging gives the coarsest grain, and an exposed plate the finest; between them lies the grain which is given by a moderately exposed sensitive film.

If the washing of the plate after the first drying is omitted, then it always carries with it a small quantity of potassium bromide after leaving the silver solution and also some potassium nitrate. In this case the appearances are more or less similar to those which follow the addition of potassium bromide. I have not studied the effect of potassium nitrate on development. There is no fear of free potassium iodide in the sensitive film, because during the precipitation of the silver haloids it will be completely changed into silver iodide and potassium nitrate before the bromide can separate itself out.

If potassium iodide is added to the developer the image appears very quickly—seldom, however, without fog. If the development is not stopped at the right time the fog increases until the image disappears from sight, notwithstanding that it is still easily visible by transmitted light on account of its unusual density. In most cases the fog begins at the edges of the plate, so that the middle of the plate is also more transparent after fixing.

The quickness with which the image appears and its great intensity, in consequence of which more details are visible in the developer than on a less intense plate, led me at first to the belief that potassium iodide would allow of a notable decrease of exposure. But comparative trials showed that the gain is small. The increase of density is of greater importance. Only the lines developed with potassium iodide have such fuzzy edges that they are badly adapted for sharp measurements. Their grain is enlarged, and partly on account of the foggy ground, not sharply defined. In other cases, plates which are wanting in intensity and too transparent under the microscope to permit of being distinctly focused answer the purpose better if developed with potassium iodide than is otherwise possible.

But little iodide should be added to the developer, as otherwise the plates may become covered in a few seconds with such a thick fog that only the high lights of the image remain perceptible. I use a 1 per cent. solution and for each 3^{cc} of pyro solution 1 to 2 drops of the iodide.

Potassium bromide checks the fogging tendency of the iodide, but only slightly. With 6 drops of bromide solution (1:20) to 3^{cc} pyro solution the fogging caused by one drop of potassium iodide (1:100) could barely be checked.

Potassium chloride lessens the fog, but also the sensitiveness and intensity. The disadvantages, unfortunately, outweigh the advantages. It is so at least with silver-bromide, to which in this case my experience is limited (one trial).

A developer containing gelatine tends to a fine-grained image and also checks the formation of fog. Toward the end of the development potassium bromide may be added without fear of enlarging the grain. If the bromide be present from the commencement the image acquires great clearness, but comes up slowly. If the plate contains silver-iodide the grain enlarges under the influence of the bromide. My developer contains 2^{cc} of solution of gelatine (1:50) to 3^{cc} of pyro (one trial).

Ammonia employed as a preliminary bath heightens the sensitiveness and intensity of the silver bromide. The lines will be clearer, the ground of the plate lighter, although it shows larger spots than an unbathed plate does. This mode of sensitizing does not answer in practice because the bathing (15 minutes in 150^{cc} water and 1^{cc} ammonia) and the subsequent drying, take up too much time (one trial).

The general result of my experiments in developing leads to the use of a largely diluted developer and little bromide with a good exposure, but above all short development.

VII.—THE FIXING.

The fixing is done in a solution of hyposulphite of soda (1:4), and proceeds much quicker than with ordinary dry plates. My small plates for photographing the spectrum in a vacuum readily fix in a few seconds. It is only when the film contains iodide that minutes are required. Silver iodo-bromide plates should always be kept horizontal and lie in the fixing solution face downwards, so that the silver-laden solution may fall quickly to the bottom and make room for fresher and more active solution. For this purpose evaporating dishes are most suitable, and if chosen of suitable size they have the further advantage that the plates as they lie can only touch the dish at the edges and corners and not on the surface, and can more easily be laid hold of and taken out of the bath without damage—an advantage not to be underrated with small sizes. I prefer to employ two baths, the second for the after-fixing. In this way the negative does not require so much washing and keeps better. By long use the bath works more slowly, especially in fixing plates containing iodide. In this case a new bath should be made.

Plates without a binding material require very careful handling to prevent the image from floating away. In this case the film side must naturally be placed uppermost. When all the bromide is dissolved the best plan is to remove the fixing solution with a syphon. The dish must not be shaken; it may be inclined a little at the last, as much as is necessary to run off the remaining fluid from the plate. The same care is necessary during the subsequent washing. When it is allowable, such films may be set fast with a gelatine bath after development. The fixing will be made very much easier thereby.

VIII.—WASHING AFTER DEVELOPMENT AND AFTER FIXING.

If the plate has been coated with gelatine and the silver bromide also contains gelatine, then it will stand a pretty strong stream of water without damage. In any case it can be washed without hesitation in abundantly flowing water. Greater care is necessary if there is no gelatine coating or if the sensitive bromide contains no gelatine, especially if it is in a thick layer. In this case standing water is better. As a rule, the film stands better than one would expect.

After development I wash only a few seconds, and when it is desired to suddenly stop the development I plunge the plate into the fixing bath without washing. I keep fixed plates in a stream of water from one to two minutes, and this is generally enough to remove the fixing salt. Larger sizes will take more time. I work with small plates only, and these dry on blotting paper in two or three minutes. Most of the water runs down to the bottom of the plates, and is absorbed by the paper. The rest I shake off or let it soak into a slip of blotting paper which I put on the edge of the plate.

Care must be taken not to touch the film with the finger while it is wet. It is very easily damaged in this way, although it will resist a stream of water.

If the plate is required to be dried off quickly, which is desirable for the better preservation of the sharpness of the image, then after the water has drained off I hold it close to a stove or lamp-chimney. There is no fear of the film melting, as with a gelatine dry plate.

IX.—THE NEGATIVE IMAGE.

The negative image forms a lusterless relief of a dark gray or brown color. By rubbing with the finger, or better with some hard substance, it becomes like polished silver. Even dusting with a soft brush will often cause glittering silvery lines to appear. If the silver bromide contains no gelatine the surface of the image is much more tender, and the employment of a brush to remove dust, etc., is quite impossible. (With plates containing gelatine the silver film worked over with a burnisher gives, after a few strokes, a bright, silvery film which is so resisting that it may be highly polished with a leather and rouge.) The image may be further protected by a coat of varnish or gelatine, but not without damage to the sharpness. This is the case at all events with line spectra. The conditions are not the same as with ordinary dry plates, in which the image is within the gelatine film; in the new plates it is more like a small silver rod on the gelatine coating. The silver particles which compose this little rod lie thickly and closely together in the best of my pictures. Hence they show such extraordinary sharpness under the microscope. As soon as the varnish runs over these small rods it causes a swelling which naturally must have some injurious influence on the definition of the edges of the lines upon which it falls.

X.—THE INTENSIFYING.

Plates with a very fine grain sometimes fail in density. In this case they must be intensified. I hoped at first to be able to use silver intensification with advantage, but the trials did not answer my expectations. I have, however, obtained satisfactory results by bathing the plates in a solution of mercury bichloride 1 : 50, well washing, and then treating them with dilute ammonia at 1 : 10, followed by copious washing. As a rule the intensifying of spectrum negatives is not to be recommended, because it deprives them more or less of their original character and delicacy. The image should always derive the necessary density from the developer.

XI.—SENSITIVENESS.

I have at present very few observations ont his point. Until quite lately I did not have the vacuum apparatus necessary for the proper treatment of this subject. Such of my results as are of importance for the purposes of this paper I give below.

Silver bromide is, as already stated, made more sensitive by the presence of silver iodide and gelatine. The same result occurs whether it settles in gelatine or if the grains of silver bromide are in contact with gelatine on one side only. Its sensitiveness is considerably increased thereby.

Plain glass plates were coated on one half with gelatine, and silver bromide was allowed to settle on them as before described, so that one half of the plate had a coating of gelatine with silver bromide above it, while the other was coated with the bromide alone. The two halves touched each other in a straight line which equally divided the image of the spectrum into two halves in the direction of its length. Each exposure gave a complete spectrum on both halves of the coating. When exposed to the spectrum of the Sun the gelatine half showed itself certainly four or five times more sensitive than the glass half. (If the gelatine coating shows any bubbles that have burst and left plain glass, the precipitated silver bromide will be less sensitive in such places and show lighter points and circular spots. Bromide containing gelatine does not show this defect.)

These pictures were repeated with silver bromide that had been precipitated in presence of ammonia, as well as with some that had been precipitated from a solution containing gelatine. Attention was also paid to the thickness of the film of silver bromide. With the silver bromide that had been treated with ammonia the same difference between the two halves appeared as before, but, on the other hand, with that containing gelatine the gelatine substratum, as might have been expected, produced no effect. The explanation of this is easily understood; the sensitiveness of the silver bromide is so greatly increased by its being precipitated from gelatine and surrounded by it that the very much weaker action of the gelatine substratum has no visible effect. The same thing is observed with silver bromide free from gelatine, when it is exposed in films of greater thickness. Hence it is also easy to see that in this case the photo-chemical action of the rays of light only reaches the outer layer of the film which does not come under the influence of the bromine-absorbing action of the gelatine (H. W. Vogel), like the particles of bromide deposited directly upon the gelatine substratum. In this case the action on the two halves of the plate must be exactly the same.

The new plates are not very sensitive to sunlight. At a height of 120 meters above mean sea level (Leipzig) I obtained with a June Sun wave-length 2939.7, and with highly sensitive dry plates under the same conditions, with only a third of the exposure, wave-length 2937.0.[1]

With an exposure of such duration (forty minutes) as was necessary for this, the spectrum on the ultra-violet sensitive plate breaks off sharply as an opaque band of action at wave-length 2973.8 and runs on further from there in distinct lines on a clear ground as far as wave-length 2939.7. This clear glass ground in the neighborhood of the most refrangible ultra-violet rays of the Sun is an advantage of the new plates. Under the same circumstances ordinary plates give thick fog, in which the most refrangible lines become first of all indistinct, and if an effort is made to photograph them more clearly by longer exposure they disappear entirely. On account of this defect the observation of the most refrangible rays of sunlight on ordinary plates is made considerably more difficult. At the same time, they are always to be preferred on account of their greater sensitiveness.

The new plates can only come into question in cases where they excel both in intensity and in sensitiveness. This first occurs at wave-length 2200, and from this point onward their sensitiveness increases. Consequently their greater working power is more in their unusual intensity, and is based on the fact that, in consequence of their small sensitiveness for the less refrangible rays, there is nothing to hinder their being exposed for a long time without becoming thickly fogged as ordinary dry plates do. The origin of this fog is diffused light arising from the inside of the prisms and lenses of the spectroscopic apparatus, of which the principal part consists of rays for which gelatino-silver bromide emulsion is much more sensitive than pure silver bromide.

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[1] Both lines belong to the extension of the ultra-violet solar spectrum discovered previously by Herr Oskar Simony. I took their wave-lengths from the drawing published by A. Cornu in the *Comptes Rendus* (111) of this part of the spectrum extending to wave-length 2922.2, which was made from Simony's original photographs.

Since the use of gelatine so distinctly improved my pictures of the less refrangible rays of the new spectral region there was no reason for excluding it in the opening up of the remaining part of the spectrum as far as wave-length 1000. My attention was first of all attracted by its presence about the limits of action of the plates employed. Circumstances have unfortunately not yet allowed me to approach more closely a solution of this question.

The resumption of my experiments on plates should quickly settle the behavior of pure silver bromide with regard to wave-length 1000, and, as the following considerations will show, there is some hope of success.

If one considers that gelatine, even in a thickness of only $0^{mm},00004$, sensibly weakens the rays of wave-length 1852, and that in even much thinner layers it apparently stops all photographic action of ordinary dry plates near wave-length 1820, and on the other hand that the course of its absorption curve between $\lambda 2200$ and $\lambda 1820$ shows no increase, but rather a lessening of its transparency for the rays of the more strongly refrangible region, it is quite surprising that in spite of this it should be practicable to photograph the extensive region of the smallest wave-lengths, as I have ventured to designate the part of the spectrum lying between 1852 and 1000, by means of gelatine. An explanation of this is to be found only in the sensitizing action of the gelatine, which possibly gets the upper hand in the struggle with absorption, and begins to lose it where the range of action of the new plates ends.

Under these circumstances it may be expected that the discovery of the unknown spectral region beyond wave-length 1000 is reserved for the pure silver haloid. Gelatine will, however, in this case also hardly be superfluous, because when used as a substratum it forms the only possible means of increasing the sensitiveness.

XII.—THE KEEPING QUALITIES OF THE PLATES.

I have kept plates prepared in different ways for a long time in order to test their keeping qualities from time to time. They were kept unpacked in a light-proof cupboard, and consequently were not protected against the action of the atmosphere. From my experience with gelatine emulsions I was afraid they would show unevenness in their coating, and, above all, increased fog around their edges and a greater development of the imperfections of their surfaces. Pictures taken with them show, however, the contrary. The plates work even more cleanly after keeping than when freshly prepared, and some kinds were even more sensitive. I did not, however, make comparative trials with the sensitometer. My experience is founded only on the photographic pictures of the new rays beyond 1850. According to this the new plates can be kept quite as long as ordinary dry plates. Compared with those coated with an emulsion containing silver oxide and ammonia they show even far superior keeping powers.

ON THE EMPLOYMENT OF PLATES SENSITIVE TO THE ULTRA-VIOLET.

The plates were intended from the very commencement for photographing the spectrum, and have hitherto been used for that purpose only. How they answered (and not less; in what points they still failed) is shown in the foregoing account, and further in my former paper I have pointed out their good and bad qualities impartially, because I did not wish to promise more than they could be trusted to perform. I therefore consider disappointments in their use as entirely excluded from discussion.

As a measure of their actual capabilities the spectra 11 and 12 on Plate V. of the above-mentioned paper[1] may be referred to. It may, however, be remarked that the definition of these spectra has suffered from defects in the crystal of the fluor-spar prism employed, and that the same plate exposed to the diffraction spectrum has given a clearer picture. A proof of this is afforded by my enlargements to more than three hundred times of the diffraction pictures of the rays 1620.

The sharpness of my negatives has here and there led to the belief that the new plates can be used advantageously for astro-photography. Against this, however, there are two important obstacles, the want of sensitiveness and the formation of a round grain in the negative.

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[1] *Sitzungsberichte K. Akad. d. W. Wien*, Bd. CII, Abth. II, *a*: "*Uber die Photographie der Lichtstrahlen kleinster Wellenlängen*," Part 2, 1893.

For the rays of light with which astro-photography has to do the plates hitherto in use are many times more sensitive than the new ones. The use of the latter could only be thought of with considerably prolonged exposures. Astro-photography, however, requires the exact opposite—shortening of the exposure. Further, the disk-shaped negative grain arising from chemical fog, as has already been fully explained, is so like the picture of a star that some of my plates have quite the appearance of a picture of the starry heavens. Under such circumstances mistakes could hardly be avoided in star pictures. In that case, too, the precautionary measures that have hitherto been employed for recognizing defects of the plates will not have the desired effect, because the grain alluded to often comes out very strongly. Both defects outweigh the advantage of greater sharpness of image to such a great extent that the new plates cannot be recommended for astro-photography, and for professional photography, still less. The only use they might find would be for line reproductions. The perfect sharpness with which they reproduce lines and their absolute opacity would certainly place them in the first rank for this, if the preparation of faultless films over large surfaces did not only involve considerable difficulties, but was also too costly and took up too much time to pay.

I have not used them for portrait or landscape photography, but for the same reasons, and still more on account of the want of half-tones, they are quite unsuitable for such purposes.

They completely fulfil only their original object: the observation of the rays beyond wave-length 2200. But for this purpose they are at present unrivaled.

V. SCHUMANN.

Lord Rosse's lecture before the Royal Institution, on the radiant heat from the Moon during the progress of an eclipse, has been printed in pamphlet form. The author gives an exceedingly interesting review of his early observations, and compares his results with the later work of Langley and Boys, by which they are in general confirmed. An unexpected result, and one which is still unexplained, though confirmed by subsequent observations, was the fact that the Moon did not regain its full heat after an eclipse. From the low coefficient of transmission of glass for lunar heat, Lord Rosse inferred that most of the heat is derived from solar rays which have been absorbed and re-radiated by the surface of the Moon, and not merely reflected by it, and Langley's subsequent measurements in the lunar heat spectrum led to the same conclusion.

The lunar heat phase-curve determined by Mr. Very agrees nearly with that of Lord Rosse, though he had the latter curve to guide him. (It is not clear how this could affect the form of the curve). The greatest heating effect is not found after the time of full Moon, as might be expected, but for some cause (possibly accidental), a little before it.

The apparatus used by the author consists of two thermopiles, each with a condensing mirror, swung in front of a three-foot reflector, and it is evidently much less sensitive than that employed by Langley, who measured the distribution of heat in the lunar spectrum with a beam only ten inches in diameter. The radiomicrometer can be used only in a fixed position, and therefore in connection with a heliostat; experiments with a bolometer were only partially successful, and Lord Rosse thinks that a thermo-couple, with sufficiently sensitive galvanometer, would be better adapted to his purposes than either of these instruments.

Reviews.

NEW BOOKS ON THE SPECTROSCOPE.

La Spectroscopie. Par JULIEN LEFÈVRE, Professeur à l'École des Sciences et à l'École de médecine de Nantes. Small 8vo, pp. 188. Paris: Gauthier-Villars et fils.

La Spectrométrie. Appareils et mesures. Par JULIEN LEFÈVRE, Professeur à l'École des Sciences et á l'École de médecine de Nantes. Small 8vo, pp. 212. Paris: Gauthier-Villars et fils.

Die Spectralanalyse. Von Dr. JOHN LANDAUER. 8vo, pp. viii+174. Braunschweig: Friedrich Vieweg und Sohn, 1896.

THE small books by Professor Lefévre form two of the numerous volumes of the *Encyclopédie scientifique des aide-memoire*, published under the direction of M. Léauté, Membre de l'Institut, and therefore seem intended to serve as guides to the student, or to the general reader seeking technical information. The first volume is devoted to spectroscopic results, the second to instruments, and to results which depend upon exact measurement; but the distinction between qualitative and quantitative work is not a very satisfactory basis of classification in spectroscopy, and in the arrangement of these volumes it is by no means carefully observed.

The preface to *La Spectroscopie* informs us that the author has undertaken to bring together results scattered through numerous memoirs, especially those of recent date, and that "Le lecteur trouvera donc ici . . . . tout ce qui se rapporte aux spectres d'émission et d'absorption des corps simples, au spectre solaire, aux spectres invisibles, aux mouvements et à la constitution des astres." After this assurance we are somewhat surprised to find that many, if not most of the recent results of spectroscopic investigations are conspicuously absent. Thus, the chapters on the spectra of the elements represent a stage of progress which has long been passed. They are mainly devoted to the pioneering work of Lecoq de Boisbaudran, and contain nothing later than the measures of Thalén. No reference is made to the researches of Kayser and Runge, Rydberg, Eder and Valenta, Hasselberg or Rowland. The wave-lengths are from old tables, and no hint is anywhere given that corrections are required to reduce them to the modern standard. In the identification of solar lines no advance beyond the work of Ångström is indicated. In solar spectroscopy Hale's photographs of prominences and faculæ have no place. The spectroscopy of stars and nebulæ is that of Secchi's time, and the only astronomical spectroscope described and illustrated in the book is of value only on account of a certain amount of historical interest, and as an example of what should be carefully avoided in designing a modern instrument. There is no reference to the researches of Vogel and Scheiner on the motion of stars in the line of sight, or to Pickering's photographs of star spectra and discovery of spectroscopic binaries. The chapter on the infra-red spectrum does not mention the wave-length determinations of Paschen and of Rubens, nor that on the ultra-violet spectrum the important investigations of V. Schumann. Were it not for a few references to recent results that have been published in French journals, the book might have been written twenty years ago.

In the second volume the theory of the spectroscope is developed, and many forms of instruments are described and illustrated. Considerable space is given to the half-prism and to the Thollon couple. Here the treatment is interesting, and, in some respects fairly satisfactory. But the theory is developed entirely from the standpoint of geometrical optics (except, of course, in the case of the diffraction grating); hence there is no reference to the resolving power of a spectroscope, the most significant of its properties. Hence, also, the lack of a guiding principle, by which the student can estimate the relative efficiencies of the different forms of instruments described, and decide which of them is best for any particular purpose. In the absence of such a principle the author himself frequently falls into error, as for example in the statement that the same results can be obtained with three or four compound half prisms as with fifteen or twenty prisms of the ordinary form.

The account of the results of spectroscopic measurements, which forms the latter half of the book, contains much more of modern work than the preceding volume; but between recent results and the early investigations to which the greater part of these two volumes is devoted, there is a gap which cannot be bridged over without a more attentive study of English, German and American scientific literature.

Dr. Landauer's handbook more nearly represents the present state of spectrum analysis. It is a reprint, with some alterations and additions, of an article contributed by the author to the *Neues Handwörterbuch der Chemie* of Drs. Fehling and Hell, and prominence has naturally been given to the chemical aspect of spectroscopy. The greater part of the book is devoted to the spectra of the elements and their compounds, and to the excellent treatment of this subject the value of the book is mainly due. Under each substance is given an account of its spectral peculiarities, with a brief historical notice; the tables of wave-lengths embody the results of the most recent measurements, and are followed by copious references to original sources of information. All wave-lengths are expressed in tenth-meters, and, when necessary, have been reduced to Rowland's scale. The most useful instruments for laboratory purposes, including the concave grating spectroscope, are described and illustrated, but the theory of these instruments is very lightly touched upon.

The astronomical applications of the spectroscope occupy only a few pages, which bear evidence of having been compiled by one who has little practical familiarity with the subject. They are however of minor importance from the standpoint of the author, and a satisfactory treatment would in any case be impossible with the same restrictions as to space. The present state of science is in general fairly well represented, and in one place, on page 155, where the photography of the corona in full daylight is mentioned as an accomplished fact, the author even runs a little ahead of the times.

J. E. K.

Ueber das Spectrum von Mira Ceti. Von H. C. VOGEL. Sitz. d. K. Akad. d. W. Berlin, 17, 395–399, 1896.

IN this short paper Professor Vogel gives the results of measurement of a number of photographs obtained by Professor Wilsing with the Potsdam spectrograph. The upper part of the spectrum closely resembles that of the Sun; in the lower part, toward F, the deviation from the solar spectrum becomes more pronounced, and the bands characteristic of the type IIIa begin to appear. All the hydrogen lines are bright, and very strong and broad, with the exception of *Hε*, the place of which is occupied by the strong absorption line H of calcium. Professor Vogel accepts Miss Clerke's explanation of this remarkable spectrum, remarking however that the existence of a relatively cool layer of calcium vapor over the hydrogen envelope is conceivable as representing only a temporary state of the star's atmosphere, and that it is important to ascertain whether the bright lines are visible at other times than those of the star's maximum brightness.

A slight displacement of the hydrogen lines toward the red was suspected, but could not be verified on account of the small scale of the photographs. No absorption lines accompanied the bright hydrogen lines, except in the case of $H\zeta$, which resembled the same line in β Lyræ. No other bright lines were shown on the photographs.

The paper concludes with a table of wave-lengths and comparisons with solar lines.

Notes on the Nebular Theory in Relation to Stellar, Solar, Planetary, Cometary, and Geological Phenomena. By WILLIAM FORD STANLEY. 8vo, pp. 260. London: Kegan Paul, Trench, Trübner & Co., 1895,

ACCORDING to a statement in the preface, this book is based upon a series of papers which were regarded by orthodox authorities as too speculative for communication to the learned societies. The author therefore makes no very high claim for them, although his purpose—to establish a modified form of the Nebular Theory of Laplace on certain new ideas and calculations of his own—is sufficiently ambitious, and would seem to require the application of somewhat more rigorous methods.

After a few pages devoted to the views of Wright, Kant, Laplace, and later philosophers, the author proceeds to develop his own ideas. As it is difficult to account for the phenomena presented by the nebulæ, considering their extreme tenuity and the accepted dimensions of the atom, a still further subdivision of matter is postulated. Matter in this ultimate state of dissociation exists as a "pneuma," and the dissociation-unit is a "pneumite." The pneumites are all of the same size. They have one vibration period only; they have the same capacity for heat, and many other properties in common, which are minutely described and illustrated in chapter ii. It is rather disheartening to the reader to find that "the state and associations of such pneumites will now be considered as the groundwork of the nebular theory to be proposed."

In fact, in the development of the theory which follows we have a detailed history of what may or may not be the actual processes of nature. While some of the author's ideas are novel and interesting, and may prove to be of value, others certainly run counter to well-known mechanical and physical laws. The last few chapters deal with geological rather than cosmical theories.

The style is unattractive, and frequently obscure. The reader finds his patience tried by whole sentences that have to be read more than once in order to extract their meaning, and he cannot avoid a feeling of relief when he lays the book aside.

Observations de l'Éclipse Totale du Soleil du 16 Avril, 1893. H. DESLANDRES. (Mémoire extrait des *Annales du Bureau des Longitudes*, t. V.)

THE eclipse of the present month lends additional interest to the report presented by M. Deslandres at the beginning of the year to the Bureau des Longitudes, and now fresh from the press of Gauthier-Villars. Two expeditions were sent to Senegal by the Bureau des Longitudes for the purpose of observing the phenomena of the total eclipse of 1893. One of them, under the leadership of M. Deslandres, was to devote its entire attention to astrophysical observations, while the other was to confine its programme to those of astronomy of position. The present report gives the details of the methods employed in obtaining the results already published in the *Comptes Rendus.* The volume of seventy-seven pages is divided into four chapters, of which the first three describe the object and organization of the expedition, the journey and establishment of the station at Fundium, and the results obtained, while the fourth is devoted to general remarks on the solar atmosphere. The work is illustrated by three heliogravure plates, which are reproductions of photographs of the eclipse station and of the inner and outer corona.

The object of the expedition comprised investigations (*a*) of the form and brightness of the corona, (*b*) of its spectrum, especially in the ultra-violet region, and (*c*) of its rotation. For the direct photography of the corona four objectives were employed, ranging in aperture from

$0^{m}.08$ to $0^{m}.12$ and in focal length from $0^{m}.60$ to 3^{m} One of these, an objective by Zeiss with a field of 30°, was used with the idea of revealing a possible intra-Mercurial planet. Of the eighteen successful negatives obtained, those made on plates of mean sensitiveness gave the best results, while on the most sensitive plates the background of sky is too intense and the details are less clearly visible. Certain of the latter plates, however, which received short exposures, show perfectly the prominences and the inner corona. Three of the negatives have upon them a series of squares due to progressively increasing exposures to a standard lamp, made before the eclipse. On one of these plates there have been traced three curves, the points of which have respectively the same brightness as the squares corresponding to the exposures 4^{s}, 8^{s} and 12^{s}. After taking into account the diameter of the objective, and its absorptive effect, it was found that the part of the corona lying between circles 3′ and 9′ 30″ from the limb equaled in brightness 0.18 of a "bougie décimale" placed at a distance of one meter. The simplicity of this photometric method is a strong point in its favor, but we unfortunately have the testimony of some who have used it in tropical countries that the results obtained in this way cannot always be given very great weight.

The negative obtained with the Zeiss wide angle objective covered a field of 30°, and clearly showed the planets Venus and Jupiter, the latter 9° distant from the Sun. It could not be determined whether other black points upon the plate were stars or photographic defects, and M. Deslandres consequently recommends that hereafter such objectives be used in duplicate, so that the results may be compared.

In his remarks on the forms of the prominences photographed during the eclipse, M. Deslandres has paid some attention to the question of the "white" prominences of Tacchini. His conclusion, based upon a comparison of the portrait lens and objective prism photographs, is that if prominences are accompanied by dust emitting a continuous spectrum, the image of the dust cloud is identical with that of the gas. He does not agree with Professor Schaeberle that prominence photographs taken without an eclipse fail to show the essential details of structure, but maintains the opinion also recently expressed by the reviewer in these pages, that if suitable precautions are taken the images will be very similar to those made during totality.

As for the form of the corona, the images obtained with the portrait lenses were found to agree closely with the South American photographs of Schaeberle, showing that the changes which are known to take place in the coronal structure do not ordinarily occur within a few hours. The corona of 1893 agreed with those of 1871 and 1882 in demonstrating that the curved polar rays and marked equatorial extension which are characteristic of minima of spot activity are replaced at times of maxima by approximate uniformity of extent in all directions.

In the section on the composition of the coronal light M. Deslandres reviews at some length the observations made at previous eclipses before describing his own work. In all, five spectrographs were employed; three of them received light from the mirrors of a polar heliostat, upon the axis of which a fourth was mounted. The fifth was carried on a small equatorial mounting. With the spectrograph having one flint prism a photograph was obtained showing a continuous spectrum crossed by thirteen bright lines between λ 5000 and λ 3800. Of these four are of unknown origin, while the remainder belong to hydrogen, calcium or helium. No dark lines were shown. Nearly the same portion of the spectrum was included in a photograph taken primarily for the purpose of determining the rotation of the corona, with a spectrograph having three flint prisms. On this plate the spectra of regions between 3′ and 10′ from the limb on opposite sides of the Sun were photographed for comparison. Although equal exposures were given in the two cases, fifteen bright lines were shown on the east and but eight on the west side of the Sun. The calcium (H and K) and the hydrogen lines were strongest on the west side, but other lines of unknown origin were equally strong on both sides. Moreover, a comparison of the bright lines photographed with the one prism and the three prism spectrographs, which received light from different parts of the corona, shows an apparent difference in the gases represented in the two cases. The ultra-violet spectrum as far as λ 3089.2, or about the limit of the solar spectrum, was photographed with a spectrograph having a single prism of Iceland spar. Here, as in the two previous cases, no dark Fraunhofer lines were obtained. The intensity of the spectrum was greatest in the blue, and diminished rapidly toward the ultra-violet. A comparison of this spectrum with one of the disk, obtained with the same apparatus, showed that the decrease of intensity toward the ultra-violet was more rapid in the former plate. Thus the maximum of intensity of the coronal spectrum is probably displaced toward the red, on account of the lower temperature of the coronal region. Thirty-eight bright lines, most of them of unknown origin, were photographed between λ 3628.1 and λ 3089.2.

The third piece of work with which M. Deslandres busied himself was an attempt to determine spectroscopically the velocity of rotation of the corona. Of the two spectroscopes employed the first had a 4-inch Rowland grating and quartz lenses of $1^{m}.30$ focal length. With this instrument, on account of the faintness of the spectra, no results were obtained. The second spectroscope, having three flint prisms, was carried by a 6-inch equatorial mounting. The slit, placed parallel to the solar equator, was so arranged that each half could be alternately exposed to the corona, the solar image being moved between the exposures so as to bring points in the corona respectively 10′ distant from the east and west limbs of the Sun, upon the center of the east and west halves of the slit. The negative obtained with this instrument showed images of the H and K lines sufficiently strong for measurement. The lines given by opposite parts of the corona were displaced with reference to each other an amount corresponding to a difference in velocity of $6^{km}.8 \pm 1^{km}.2$. M. Deslandres concludes from this that the corona at the equator closely follows the disk in its motion, *i. e.*, that the corona moves as though it were a solid rigidly attached to the photosphere. Various objections have already been raised by several writers to the validity of this conclusion, to some of which M. Deslandres replies. It is not likely that the displacement can be attributed to the change of temperature during totality. The apparatus was well protected against temperature variations, and laboratory experiments made under similar conditions revealed no sensible displacement. The objection that the H and K lines are not truly coronal, but are due to diffusion of the light of the chromosphere and prominences, is a much more serious one. M. Deslandres points out in the first part of his memoir that the atmosphere was very hazy during the eclipse, so that we may conclude from the experience of earlier eclipses that the diffusion must have been very appreciable. As much of the diffuse light in each part of the corona observed must have come from the neighboring chromosphere and prominences, there must have resulted a certain relative displacement of the lines somewhat less than that observed by M. Deslandres. If, as seems not unlikely, the probable error of the measures is larger than the value given, the result would be left much in doubt if it is held that the H and K lines were due to diffusion. Professor Lockyer, from the observations made by the English party at the same African station, concludes that the H and K lines do not properly belong to the coronal spectrum.

Moreover the remarkable results on the solar rotation recently obtained by Mr. Jewell, briefly referred to on another page, can hardly be reconciled with M. Deslandres' conclusion that the photosphere and corona rotate together like a rigid mass. It is to be hoped that a repetition of the experiment will soon be made by M. Deslandres. If, as is suggested in the memoir, it is found possible to use the fourth spectrum of a 6-inch grating, and to determine the motion in the line of sight by measuring the inclination of the coronal lines with reference to fixed lines of comparison, as Professor Keeler and M. Deslandres have done in the case of Saturn's rings, the mode of rotation of the corona should be placed beyond a doubt. With such dispersion it may also be possible to draw some trustworthy conclusions regarding the rotation of the corona from the unsymmetrical diffuseness of the edges of the coronal lines, as the author also points out.

The remainder of the memoir is devoted to a general discussion of solar phenomena and a review of various solar theories. M. Deslandres finds great difficulty in accepting Professor Schaeberle's explanation of prominences, as the structure required by this theory is not often met with in daily observations of these objects. He also refers to a fact by no means in harmony with this theory, *i. e.*, the bright lines photographed on the Sun's disk show no such displacements as Professor Schaeberle's conclusions would lead us to expect. M. Deslandres himself believes in the electrical origin of the chromosphere, prominences and corona, an idea which since the very beginning of prominence observations has been held by many solar physicists. The electrical hypothesis is founded upon the apparent fact that the characteristic spectrum of hydrogen can be produced only by means of an electric discharge. It is true that Professor Hartley has recently announced that he once observed the $H\alpha$ line in the spectrum of the flame of a Bessemer converter. "Mais, en examinant avec soin toutes les conditions de l'expérience, on a reconnu que, à ce moment, l'atmosphère ambiante subissait une tempête de neige et par suite une perturbation électrique. Ce fait isolé confirme donc le résultat précédent, et l'on doit admettre comme presque certaine la conclusion suivante: la lumière des protubérances a une origine électrique." Thus does M.

Deslandres (p. 65) dispose of a difficulty in the path of the electrical hypothesis. In the opinion of the reviewer this interesting observation merits further consideration.

The electrical hypothesis explains not only the prominences, but the chromosphere and corona as well. Both give bright line spectra, and are thus allied to the prominences. To account for the electrical condition of these objects M. Deslandres finds an analogy in terrestrial atmospheric electricity. The difference of potential from the top to the bottom of the Eiffel tower varies between 3000 and 30,000 volts. In the hotter and more highly conducting atmosphere of the Sun a much greater (?) difference of potential may reasonably be supposed to exist; whence a continuous luminous discharge, producing the phenomenon of the chromosphere. Prominences correspond to electric storms. Terrestrial atmospheric electricity is generally attributed to the relative motion with respect to the Earth of the various strata of the atmosphere. If the same hypothesis is applied to the Sun it furnishes an explanation of the mode of rotation of the corona observed by M. Deslandres at the eclipse of 1893. For if the atmosphere did not closely follow the disk in its motion, the induction phenomena produced by the relative movements of the gas and floating dust would, according to the law of Lenz, develop opposing mechanical action, and thus tend to bring about uniformity of rotation.

In thus outlining an electrical hypothesis which possesses many interesting and instructive features, M. Deslandres does not discard all mechanical theories. On the contrary, he seeks in the well-known theory of Faye an explanation of the spots, the photosphere and such eruptive prominences as cannot be explained on purely electrical grounds. In the corona other difficulties are encountered. However, the coronal streamers are considered to be similar in nature to the cathode rays produced by electric discharges in rarified gases. The brilliant regions of the chromosphere emit cathode rays which are more active than those of neighboring less-luminous regions: these leave the chromosphere in nearly normal straight lines, and illuminate by phosphoresence the dust scattered through the coronal atmosphere. The curved forms of the rays are due to the magnetic field and to mutual repulsion. M. Deslandres has compared photographs of the corona made at the 1893 eclipse with photographs and drawings of the faculæ made on the same day, with a result similar to that recently obtained by Professor Schaeberle from the same data: the coronal streamers seem to have their origin in the faculæ. It is pointed out, however, that this conclusion is open to considerable doubt, to remove which it will be necessary to devise some method of observing the corona without an eclipse. M. Deslandres has himself proposed a method which may ultimately prove successful: that of photographing the corona with plates sensitive only to light of great wave-length. Hitherto, however, experiments made in this direction (by Dr. Huggins many years ago) have given no valuable results. It is to be hoped that a process of preparing plates suitable for this work will soon be discovered. The bolometric method of mapping the corona proposed by Hale is described by M. Deslandres as being founded "d'une part sur la conclusion précédente relative aux rayons calorifiques, et d'autre part sur les résultats de M. Langley." As a matter of fact, the apparent advantage of the method resides in the fact that it is a strictly differential one, and therefore may perhaps remove the persistent difficulty due to the illumination of our atmosphere. In this method it matters not whether the coronal radiation be of long or short wave-length, provided only that it be sufficiently intense to affect the bolometer. In common with Professor Langley's important work a bolometer is used, but a radiomicrometer or delicate thermopile might quite as well be employed.

M. Deslandres is to be congratulated on having organized and conducted an eclipse expedition which brought home valuable results. His electrical hypothesis, while undoubtedly open to objection, may be regarded as an interesting contribution to the already long list of solar theories. The supposition on which it rests is rather insecure; it offers no explanation of prominence motions in the line of sight, and, to select but one more objection from others that suggest themselves, its manner of accounting for the coronal streamers can hardly be regarded as satisfactory. But it has the merit of indicating new points of view from which future investigations of solar phenomena may profitably be examined.

G. E. H.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

H. DESLANDRES. Observations de l'Éclipse totale du Soleil du 16 avril, 1893. Mémoire extrait des Annales du Bureau des Longitudes, 5, 77, 1896.

FÉNYI, J. A new Point of View for regarding Solar Phenomena and a new Explanation of the Appearances on the Surface of the Sun. Ap. J. 4, 18–38, June 1896.

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THE

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THE EFFECT OF PRESSURE ON WAVE-LENGTH.

By J. F. MOHLER.

IN an article[1] published in this JOURNAL (February 1896) it was shown that pressure on the arc produced a change in the wave-length of the light emitted. The results showed that in the range of pressures between one and fourteen and a half atmospheres the shift of the lines was proportional to the pressure above one atmosphere, and that it was always toward the red end of the spectrum; and also that for any one element the shift was generally proportional to wave-length.

The work has been continued to find the effect of lower pressures and also to study the effect of different methods of producing the spectra. The spectroscope, pressure cylinder, dividing engine and micrometer eyepiece used in the former investigation were also used in this work. It is but just to say that the pressure cylinder used and described in this JOURNAL (2, 116) was designed and constructed by Professor Rowland several years ago for investigating the effect of pressure on the spectra of the elements, but laid aside until he could find time for the experiment. This cylinder was fitted with a mercury gauge and a good air pump served to reduce the pressure. The pump was kept working slowly while the exposure was being made and it was easy to keep the pressure less than 2^{cm} of mercury. Almost all the measurements were made on photographic plates in the manner described in the former work. For a part of the work with cadmium a form of vacuum tube kindly furnished by Professor Michelson was used. It was the same form that he used in his determination of the length of the meter[1] in terms of the wave-length of light. An ordinary "end on" vacuum tube was also used. It contained a few centigrams of cadmium and the air was exhausted to 2^{mm} pressure. As the temperature to which the tube had to be raised to volatilize the cadmium was nearly 300° C. this pressure was about doubled when the tube was in use. Six storage cells and a Ruhmkorff coil giving a two-inch spark were used with these tubes. Most of the work was done at night, when the Physical Laboratory is comparatively free from vibration, and when consequently one can obtain better definition than at other times. For the arc light used in this night work a storage battery giving 85 volts and a low amperage was used.

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[1] W. J. HUMPHREYS and J. F. MOHLER: "Effect of Pressure on the Wave-length of Lines in the Arc-spectra of Certain Elements."

CADMIUM.

Particular attention was given to cadmium, in the hope that the discrepancy between Professor Rowland's[2] Table of Standard Wave-lengths and Professor Michelson's measurements made at Paris might be explained. The wave-lengths of the red, green, and blue cadmium lines as given by Professor Michelson's measurements of the Standard Meter are 6438.472, 5085.824 and 4799.911 Ångström units; and the values for the same lines from Professor Rowland's tables[2] are 6438.680, 5086.001, and 4800.097, giving differences of .208, .177, and .186. These values are for the wave-length in air at the standard pressure, 760^{mm} of mercury and at 16° Centigrade. These wave-lengths reduced to a vacuum would be 6440.262, 5087.238, and 4801.245 for Professor Michelson's measurements and 6440.470, 5087.415, and 4801.431 for Professor Rowland's values, giving the same differences as above.

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[1] "Détermination expérimental de le valeur du mètre en longeurs d'ondes lumineuses."

[2] *A. and A.*, 12, 1893.

A redetermination of the green cadmium line in the arc compared with the standard lines in the Sun[1] at wave-lengths 5014.422, 5015.123, 5020.208, 5022.414, 5068.944, 5074.932, 5083.518, 5105.718, 5109.827, and 5110.574 gave a result of 5086.000, which agrees with the above value.

Now if the above difference in the values of the wave-length of the green cadmium line is due to differences in the standards of length used, the other differences ought to be proportional to the wave-length, *i. e.*, for the blue line it ought to be .167 and for the red line .223, making an error of +.019 in one case and −.015 in the other: such an error as would be caused by a difference of barometric pressure of one centimeter of mercury or the expansion of the standard of length by a change of one degree Centigrade. This effect of pressure on wave-length is simply due to the fact that the index of refraction of air changes with the pressure and the wave-frequency is not changed at all. The change of wave-length noted below is of an entirely different character, and indicates a change in the vibration frequency of the waves.

The effect of decreasing the pressure on the arc producing the lines is to shift them slightly toward the violet end of the spectrum. The amount of this shift is about the same per atmosphere as it was for higher pressures, so that it could be stated that the shift of the lines varies directly as the pressure, and the standard wave-lengths would naturally be referred to a vacuum. In the former work the average *measured* shift of the green and blue cadmium lines was .010 Ångström unit toward the red for each additional atmosphere pressure. With the arc under a pressure of two or three centimeters of mercury the shift of these two lines on six different plates was .014 ± 3 toward the violet. These values were obtained by comparing the lines produced by the arc at 2^{cm} mercury pressure with those produced by the arc at $76^{cm}.36$ pressure, and also by comparing the lines from the arc at low pressure with the standard lines in the Sun given above.

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[1] Tables by ROWLAND now being published in the ASTROPHYSICAL JOURNAL.

Mr. L. E. Jewell made one set of measurements with the eyepiece micrometer on the red cadmium line, comparing it with the solar standards at wave-lengths 6431.063, 6439.298, and 6450.029, and found the shift when the pressure was removed to be .010 Ångström unit toward the violet.

With vacuum tubes the lines obtained were faint from under exposure and not good for very accurate measurement, and both tubes broke after the first heating. The plates obtained, however, showed that the position of the lines at 2^{mm} pressure produced by the spark was the same as that of the lines produced by the arc under a pressure of 2^{cm} of mercury. Professor Michelson's method of producing the light gives a much *sharper* line than can be obtained with the arc.

The shift of the ultra-violet line at wave-length 3403.77, however, was much smaller than that of the three other cadmium lines referred to above. It was a good line on all the plates, and the measured shift was about .004 Ångström unit. On looking up my original notes on the previous work at higher pressures I find that here also the shift of this ultra-violet line is much smaller than that of the lines in the visible part of the spectrum, and that the difference is much greater than would be found if the shift were proportional to wave-length. Other ultra-violet lines that occur in the cadmium series[1] were found to have a very small shift. A difference of the same kind is found in the magnesium lines and suggests a method for identifying lines of a series in an element.

MERCURY.

In the previous paper it was shown that for many elements the shift of the lines is approximately inversely proportional to the absolute temperature of the melting point. If this were true of all the elements, then mercury would have a very large shift. Several attempts to get the shift of the lines of mercury under pressure were made but the lines tried spread out too much to admit of accurate measurement. There is, however, a group of lines at wave-lengths 3650.31, 3654.94 and 3663.25[1] which are sharp when there is little material in the arc and are nicely reversed when more material is present. Ten plates of this region were taken, several under a pressure of five to six atmospheres and the others at as low a pressure as could be obtained with the air pump. These plates show that for the arc at low and high pressure the shift is proportional to pressure The shift at pressures from 2^{cm} to 3^{cm} of mercury was .005 ± 2 Ångström unit toward the violet, the position of the lines at one atmosphere pressure being taken as standard. The shift at 5½ atmospheres pressure was .020 ± 3 Ångström unit toward the red, and at 6¼ atmospheres pressure the shift was .022 ± 3 Ångström unit.

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[1] J. S. Ames: *Phil. Mag.* (5), 30, 1890.

These lines appear very sharp and clear when a spark is passed through a vacuum tube that has been exhausted by a mercury pump. Measurements of these lines on several plates taken by Dr. Ames and also on one taken by myself give results so discordant with each other and with the results given above for the arc that further work with this element will be necessary before it can be affirmed that the arc and spark produce lines of the same wave-length in a vacuum.

OTHER ELEMENTS.

The shift of the lines of many of the elements for one atmosphere pressure is such a small quantity that the measurement was attempted only when the shift was comparatively large or the lines numerous and well defined. Iron was represented on nearly all the plates by sharp lines due to impurities in the carbons, and these were always measured. The average of all these measurements of the iron lines gives a shift of .002 Ångström unit toward the violet, agreeing with the former work.

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[1] KAYSER and RUNGE, *Abh. d. K. Akad. d. W. Berlin*, 1891–3.

Indium gave us the largest measured shift under high pressure and several plates were taken of the indium lines at wave-lengths 4102.000 and 4511.345 at low pressure. Measurements on these lines showed a shift of .010 ± 4 Ångström unit toward the violet. There was one precaution, however, that it was absolutely necessary to take, which was to have the lines of about the same intensity for comparison. A heavy line at low pressure, unless it was reversed, might appear to coincide exactly with a fine line at one atmosphere pressure. In this case the unsymmetrical widening of the line was sufficient to counteract the shift due to change in pressure. This source of error was more noticeable with small pressures than with large. In general, however, the lines under low pressure were very much sharper than under heavy pressure, so that though the shift to be measured was much smaller the accuracy of setting was greater.

The shift of the zinc lines at wave-lengths 4722.342 and 4810.724 was .007 ± 3 Ångström unit toward the violet, and for the line at wave-length 3018.5 the shift was .004 ± 2 Ångström unit, agreeing well with the former work. These lines are also in the regular series of zinc triplets.

The shift of the magnesium lines of the *b* group at wave-lengths 5167.488, 5172.866 and 5183.791 was .010 ± 2 Ångström unit toward the violet; while the shift of the symmetrical group of fine ultra-violet lines at wave-lengths 2776.798, 2778.381, 2779.935, 2781.521 and 2783.077 and the pair at wave-lengths 2795.632 and 2802.805 was .006 ± 3 Ångström unit toward the violet. The shift of the strong line at wave-length 2852.239 was considerably larger, but owing to the width of the reversal could not be very accurately measured.

An attempt was made to find the shift of the compound thallium line at wave-length 5350.670, but though unsuccessful in determining the shift, it may serve to show how some compound lines may have a large *apparent* shift. The line in question is a triplet. At one atmosphere pressure with but little of the element in the arc the violet component is much the strongest and the line in the middle is the weakest. At very low pressure the red component is the strongest, and the violet component the weakest. The two thallium lines at wave-lengths 3519.342 and 3529.547 show but a small displacement with pressure.

The general effect of pressure, when the pressure was due to air, on the carbon bands was to greatly increase their strength and prominence. At high pressures the carbon bands would be much stronger than the metallic lines. At low pressures, however, they were much fainter than at atmospheric pressure and far less prominent compared with the metallic lines. The single carbon line at wave-length 2478.661, however, showed as plainly under reduced pressure as at atmospheric pressure.

In the above results the ± indicates not the calculated probable error but the actual variation in results from different plates.

I wish here to acknowledge my indebtedness to Professor Rowland and Dr. Ames, the directors of the Physical Laboratory, for direction and assistance in the investigation; also to Professor Michelson for the vacuum tube sent me, and to Mr. L. E. Jewell for assistance in the work.

JOHNS HOPKINS UNIVERSITY,
June 1896.

SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE FIRST HALF OF 1896.

By P. TACCHINI.

I TAKE pleasure in sending you a résumé of the solar observations made at the Royal Observatory of the Roman College during the first half of 1896. The weather has been exceptionally favorable. Following are the results for the spots and faculæ:

1896	Number of days of observation	Relative Frequency		Relative Size		Number of groups of spots per day
		of spots	of days without spots	of spots	of faculæ	
January	25	5.48	0.00	30.0	60.2	2.5
February	24	12.79	0.00	51.9	64.8	3.3
March	24	10.75	0.00	39.2	78.8	3.0
April	23	10.87	0.17	34.3	77.4	2.7
May	24	5.17	0.17	16.4	59.4	1.5
June	28	13.03	0.00	52.9	52.0	2.6

In comparing these results with those obtained for the six months preceding it is seen that the spots have continued to decrease, with a well-marked secondary minimum in May, while for the faculæ the difference is small.

For the prominences we have obtained the following results:

1896	Number of days of observation	Prominences		
		Mean number	Mean height	Mean extent
January	23	5.22	40″.4	2°.3
February	24	5.79	41 .7	2 .0
March	16	4.56	34 .0	1 .3
April	23	3.26	33 .0	1 .5
May	24	4.06	36 .7	1 .8
June	24	4.67	37 .3	1 .6

Thus the prominences have also shown a diminution, with a secondary minimum in April and May.

The following table contains the results which I have obtained for the distribution in latitude of solar phenomena during this period:

1896	Prominences				Faculæ				Spots			
Latitude	First Quarter		Second Quarter		First Quarter		Second Quarter		First Quarter		Second Quarter	
90° +80°	0.006	0.495	0.007	0.501								
80 +70	0.003		0.000									
70 +60	0.006		0.003		0.000	0.436	0.004	0.328				
60 +50	0.006		0.036		0.000		0.004					
50 +40	0.052		0.085		0.000		0.000					
40 +30	0.114		0.134		0.016		0.009					
30 +20	0.136		0.103		0.108		0.079		0.000	0.391	0.000	0.388
20 +10	0.114		0.087		0.172		0.123		0.250		0.245	
10 + 0	0.058		0.046		0.140		0.109		0.141		0.143	
0° −10°	0.086	0.505	0.036	0.499	0.151	0.564	0.157	0.672	0.047	0.609	0.163	0.612
10 −20	0.130		0.101		0.236		0.267		0.421		0.347	
20 −30	0.116		0.092		0.145		0.205		0.141		0.102	
30 −40	0.097		0.098		0.027		0.035					
40 −50	0.050		0.105		0.005		0.004					
50 −60	0.014		0.043		0.000		0.004					
60 −70	0.006		0.007		0.000		0.000					
70 −80	0.006		0.010									
80 −90	0.000		0.007									

The frequency of the prominences by zones was the same in both hemispheres of the Sun. The prominences were always rather numerous from the equator to ±50°, as in the preceding six months, while they were rare or altogether absent in higher latitudes. The faculæ have been most frequent in the southern zones, and always numerous from the equator to ±30°, with their maximum frequency in the zones (±10°±20°).

The spots, like the faculæ, show a greater frequency in the southern hemisphere, the maximum being also in the zones (±10°±20°), while the maxima for the prominences occur in much higher latitudes.

Only one eruption was observed: on February 5, in the southern hemisphere at — 14°.3 W.

ROME, August 1895.

CERTAIN CONSIDERATIONS CONCERNING THE ACCURACY OF EYE-ESTIMATES OF MAGNITUDE BY THE METHOD OF SEQUENCES.

By ALEXANDER W. ROBERTS.

IN an article on the light curve of certain variable stars obtained photometrically, Professor Pickering makes the following averments (ASTROPHYSICAL JOURNAL, 3, 281):

(1) When repeated observations have to be made on the same star, during the same evening, it is impossible, by the method of sequences, to obtain independent estimates.

(2) It is impossible to assign absolute values to visual determinations of magnitude.

(3) In any careful study of the causes of the variation of different stars, photometrical measurements are almost indispensable.

Put in other, and more direct language, these statements amount to this: that determinations of stellar variation by Argelander's method are usually inaccurate, generally uncertain, and always insufficient for important lines of investigation. These, if sustained, are serious charges against a method of observation that hitherto has been so zealously followed, and followed with no mean measure of success. It is unfortunate, however, that Professor Pickering should have preferred his arraignment of visual determinations of magnitude without the usual accompaniment of proof that might be accepted or rebutted, and as one cannot accept a simple *ipse dixit* even when stated by an astronomer of Professor Pickering's reputation and authority, in a matter of such importance as the question that has been raised, I think it is only due to those who, year in year out, labor to accumulate data for future discussion concerning the nature and cause of stellar variation, that such proof should be forthcoming without delay.

Meanwhile I would, from my own experience in variable star work, instance certain facts which seem to point to a different conclusion from that reached by Professor Pickering. It is to be noticed that the first statement is of more serious import than the remaining two, as it deals directly with the value of eye-estimates in determining light curves of variables of the Algol type, or of the type of U Pegasi and S Antliæ. Recently another variable of this new type has been discovered at Lovedale, and as my observations of this star supply important testimony to the reliability and accuracy of eye-estimates of magnitudes, even when a long series of measures are made on the same evening, I may be pardoned for referring to them. I am conscious that much stronger evidence could have been adduced from the observations of other variable star observers. The extreme accuracy both as to limits of variation, and times of maxima and minima, secured by Dr. Chandler from his observations of U Pegasi[1], when terms are introduced for the elimination of position error, is an instance in point. I am more conversant, however, with my own work, and I think the mode of eliminating "position error" adopted here, raises somewhat the accuracy of the observations made.

The star to which I refer is L 5861, period 7^h 16^m. The variation of this star was suspected for more than two years. In May of the present year I began systematic observations of it, the method adopted being to begin observations soon after sunset and to continue the observations at intervals of twenty minutes or half an hour, for about six or eight hours. It soon became evident that the period of the star could not be more than eight or nine hours; still the amplitude variation was so narrow, only $0^m.4$, that I determined to make no definitive discussion of the observations until I had secured a large number of them. During May, June and July, I regularly observed the star in the manner described, using no ephemeris, and with complete ignorance as to what period or type of variation the observations would yield. In July the observations were reduced, the form of the light curve being determined by a least-

[1] *Ast. Jour.*, No. 374, p. 107.

square solution of the observations, that is the observations on any evening were made to yield equations of condition of the form,

$$x + \alpha \cos t + \beta \sin t + \gamma \cos 2 t + \delta \sin 2 t = 0,$$

and the residuals, $o - c$, were computed rigorously from this expression.

The mean discordance of a single observation was found to be ± $0^m.037$.

Are we to understand that this discordance is not absolute, that it is vitiated by some unconscious obscuring of the judgment consequent upon an unconscious mental solution of over 400 equations of condition, involving seven unknown quantities, by the unconscious construction of an ephemeris from the elements obtained in this unconscious mental jugglery? Such a conclusion would be preposterous. This mean discordance of ± $0^m.037$ represents the actual face value of visual determinations of magnitude, when the method of double observations is strictly adhered to.

It is quite possible that mental bias may have influenced this result, but I would desire it to be noted that the conditions of observing were such that any bias, or predetermination of maxima and minima points, would increase the true average discordance, and thus the resulting average error ± $0^m.037$ *includes* any effects arising from this source.

I think this will be readily admitted when a detailed series of observations is given, just as they were secured. And in this connection, I would desire to point out that the varying positions of the variable and the comparison stars constantly tend to produce change in the apparent magnitudes, and thus the validity of Professor Pickering's contention, that the similarity of each succeeding observation lessens independent judgment, is strongly questioned. These arguments will be better exemplified by taking one night's observations of L 5861. (See Table (1), page 187.)

OBSERVATIONS OF L 5861 MADE ON JULY 1, 1896.

(1) TAKEN WITH A REVERSING EYEPIECE.

Time	Comparison Stars					Var. L 5861
	A. Z. C. xiv. 505	A. Z. C. xiv. 639	A. Z. C. xiv. 837	A. Z. C. xiv. 259	A. Z. C. xiv. 512	
$6^h\ 0^m$	$7^m.2$	$7^m.7$	$8^m.0$	$7^m.1$	$7^m.9$	$7^m.7$
30	7 .0	7 .6	7 .9	7 .3	7 .8	7 .6
7 0	7 .0	7 .8	8 .0	7 .4	7 .9	7 .6
10	6 .9	7 .8	7 .9	7 .6	7 .9	7 .5
25	6 .9	7 .8	7 .7	7 .6	7 .9	7 .4
45	6 .9	7 .9	7 .8	7 .6	7 .9	7 .4
8 0	6 .9	7 .8	7 .7	7 .5	7 .6	7 .3
15	6 .9	7 .8	7 .6	7 .7	7 .9	7 .3
30	6 .9	7 .9	7 .6	7 .6	7 .9	7 .3
50	6 .9	7 .9	7 .6	7 .7	7 .9	7 .3
9 10	6 .9	7 .9	7 .6	7 .6	7 .9	7 .3
30	6 .9	7 .9	7 .6	7 .7	7 .9	7 .35
50	6 .9	7 .9	7 .6	7 .7	7 .9	7 .35
10 15	6 .9	7 .8	7 .6	7 .7	7 .9	7 .4
33	6 .9	7 .6	7 .3	7 .9	7 .9	7 .6
50	6 .9	7 .6	7 .4	7 .9	7 .9	7 .6
11 15	6 .9	7 .6	7 .3	8 .0	7 .9	7 .7
30	7 .0	7 .6	7 .2	8 .0	7 .9	7 .7
12 0	7 .0	7 .4	7 .0	7 .9	7 .9	7 .7
30	7 .0	7 .4	7 .0	7 .9	7 .9	7 .7
50	7 .2	7 .4	7 .0	8 .0	8 .0	7 .8
13 20	7 .4	7 .4	7 .0	8 .0	8 .0	7 .7
45	7 .6	7 .4	7 .0	8 .0	8 .0	7 .8

If now the successive measures of the comparison stars be examined, the influence of position on the apparent magnitude will be clearly evident, and my contention that there is no danger of the mind being influenced by preceding observations abundantly proved. Indeed, if we had no other record except the above, we would naturally conclude that every comparison star used is also a variable star. The above series is, as stated, taken with an ordinary reversing eyepiece.

Let now the observations taken at the same time with a direct-vision eyepiece be examined.[1] (Table (2), page 188.)

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[1] The time of observation given in both is the mean time between the two observations.

(2) TAKEN WITH A DIRECT-VISION EYEPIECE.

Time	Comparison Stars.					Var. L 5861
	A. Z. C. xiv. 505	A. Z. C. xiv. 639	A. Z. C. xiv. 837	A. Z. C. xiv. 259	A. Z. C. xiv. 512	
$6^h\ 0^m$	$7^m.4$	$7^m.2$	$7^m.0$	$7^m.9$	$7^m.7$	$7^m.8$
30	7 .4	7 .2	7 .0	7 .9	7 .8	7 .7
7 0	7 .6	7 .1	7 .0	7 .8	7 .8	7 .8
10	7 .6	7 .0	7 .2	7 .9	7 .8	7 .8
25	7 .6	7 .0	7 .3	8 .0	7 .9	7 .7
45	7 .6	7 .0	7 .3	7 .8	7 .9	7 .6
8 0	7 .6	7 .0	7 .3	7 .7	7 .8	7 .6
15	7 .6	7 .0	7 .4	7 .5	7 .8	7 .6
30	7 .6	7 .0	7 .4	7 .6	7 .7	7 .5
50	7 .7	7 .0	7 .4	7 .4	7 .9	7 .6
9 10	7 .7	7 .0	7 .5	7 .5	7 .9	7 .6
30	7 .7	7 .0	7 .6	7 .5	7 .8	7 .6
50	7 .7	7 .0	7 .6	7 .5	7 .9	7 .6
10 15	7 .6	7 .0	7 .6	7 .5	7 .8	7 .7
33	7 .6	7 .0	8 .0	7 .4	7 .8	7 .8
50	7 .6	7 .2	7 .9	7 .4	7 .8	7 .7
11 15	7 .6	7 .3	7 .9	7 .0	7 .7	7 .8
30	7 .6	7 .3	7 .9	7 .0	7 .7	7 .8
12 0	7 .6	7 .3	8 .0	7 .1	7 .8	8 .0
30	7 .6	7 .4	8 .0	7 .2	7 .8	8 .0
50	7 .4	7 .4	8 .0	7 .0	7 .8	8 .0
13 20	7 .4	7 .5	8 .0	7 .0	7 .8	7 .8
45	7 .0	7 .7	8 .0	7 .1	7 .8	7 .6

An examination of the above series of measures indicates the operation of a systematic error similar to that which operates in Table (1). Further there is apparently no connection whatever between the measures in Table (1) and those in Table (2); and thus the independence of the various observations which Professor Pickering regards, and rightly regards, as the most valuable characteristic of photometric measurements, is also a feature of the method adopted at Lovedale. And I am convinced that it is this very independence which is the chief factor in reducing the mean error of a single combined observation below ± $0.^m04$. Further, the insecurity of measures, based solely on estimates in one position only, is abundantly manifest.

Combining, now, the apparently irreconcilable observations in Tables (1) and (2) we obtain the combined measures shown in Table (3).

(3) COMBINED MEASURES.

Time		Comparison Stars.					Total	Var. L 5861
		A. Z. C. xiv. 505	A. Z. C. xiv. 639	A. Z. C. xiv. 837	A. Z. C. xiv. 259	A. Z. C. xiv. 512		
6^h	$.0^m$	$7^m.30$	$7^m.45$	$7^m.50$	$7^m.50$	$7^m.80$	$37^m.55$	$7^m.75$
	.30	7 .20	7 .40	7 .45	7 .60	7 .80	.45	7 .65
7	.0	7 .30	7 .45	7 .50	7 .60	7 .85	.70	7 .70
	.10	7 .25	7 .40	7 .55	7 .75	7 .85	.80	7 .65
	.25	7 .25	7 .40	7 .50	7 .80	7 .90	.85	7 .55
	.45	7 .25	7 .45	7 .55	7 .70	7 .90	.85	7 .50
8	.0	7 .25	7 .40	7 .50	7 .60	7 .70	.45	7 .45
	.15	7 .25	7 .40	7 .50	7 .60	7 .85	.60	7 .45
	.30	7 .25	7 .45	7 .50	7 .60	7 .80	.60	7 .40
	.50	7 .30	7 .45	7 .50	7 .55	7 .90	.70	7 .45
9	.10	7 .30	7 .45	7 .55	7 .55	7 .90	.75	7 .45
	.30	7 .30	7 .45	7 .60	7 .60	7 .85	.80	7 .48
	.50	7 .30	7 .45	7 .60	7 .60	7 .90	.85	7 .48
10	.15	7 .25	7 .40	7 .60	7 .60	7 .85	.70	7 .55
	.33	7 .25	7 .30	7 .65	7 .65	7 85	.70	7 .70
	.50	7 .25	7 .40	7 .65	7 .65	7 .85	.80	7 .65
11	.15	7 .25	7 .45	7 .60	7 .50	7 .80	.60	7 .75
	.30	7 .30	7 .45	7 .55	7 .50	7 .80	.60	7 .75
12	.0	7 .30	7 .35	7 .50	7 .50	7 .85	.50	7 .85
	.30	7 .30	7 .40	7 .50	7 .55	7 .85	.60	7 .85
	.50	7 .30	7 .40	7 .50	7 .50	7 .90	.60	7 .90
13	.20	7 .40	7 .45	7 .50	7 .50	7 .90	.75	7 .75
	.45	7 .30	7 .55	7 .50	7 .55	7 .90	37 .80	7 .70
Mean Er. ±		$0^m.031$	$0^m.036$	$0^m.046$	$0^m.051$	$0^m.039$		

The residuals in the last line of this table accordingly represent absolute mean discordances, inasmuch as each observation is always related to the standard magnitude $6^m.8$—the limit of vision—, and there are some stars near that are just visible and no more.

One more step is taken in the discussion of a series of observations, viz., the observations are reduced to a common standard by making the totals similar, and the same correction is applied to the variable as is applied to each of the comparison stars. (See Table (4), page 190.)

The computed values in 9th column of Table (4) are calculated from the expression

$$7^m.646 - 0^m.223 \cos(\theta - 357^\circ 37') - 0^m.014 (2\theta - 156^\circ 44')$$

where $\theta = (T - 8^h\ 50^m)\ 0.^\circ 8257.$

(4) REDUCED OBSERVATIONS.

Time	Comparison Stars					Total	Var.	Var. Comp.	O.—C.
	A. Z. C. xiv. 505	A. Z. C. xiv. 639	A. Z. C. xiv. 837	A. Z. C. xiv. 259	A. Z. C. xiv. 512				
6^h 0^m	$7^m.33$	$7^m.48$	$7^m.53$	$7^m.53$	$7^m.83$	37.70	$7^m.78$	$7^m.81$	$-0^m.03$
30	7 .25	7 .45	7 .50	7 .65	7 .85	.70	7 .70	7 .72	— .02
7 0	7 .30	7 .45	7 .50	7 .60	7 .85	.70	7 .70	7 .62	+ .08
10	7 .23	7 .38	7 .53	7 .73	7 .83	.70	7 .63	7 .60	+ .03
25	7 .22	7 .37	7 .47	7 .77	7 .87	.70	7 .52	7 .56	— .04
45	7 .22	7 .42	7 .52	7 .67	7 .87	.70	7 .47	7 .51	— .04
8 0	7 .30	7 .45	7 .55	7 .65	7 .75	.70	7 .50	7 .48	+ .02
15	7 .27	7 .42	7 .52	7 .62	7 .87	.70	7 .47	7 .46	+ .01
30	7 .27	7 .47	7 .52	7 .62	7 .82	.70	7 .42	7 .44	— .02
50	7 .30	7 .45	7 .50	7 .55	7 .90	.70	7 .45	7 .44	— .01
9 10	7 .34	7 .44	7 .49	7 .54	7 .89	.70	7 .44	7 .44	— .00
30	7 .28	7 .43	7 .58	7 .58	7 .83	.70	7 .46	7 .47	— .01
50	7 .27	7 .42	7 .57	7 .57	7 .87	.70	7 .45	7 .50	— .05
10 15	7 .25	7 .40	7 .60	7 .60	7 .85	.70	7 .55	7 .56	— .01
33	7 .25	7 .30	7 .65	7 .65	7 .85	.70	7 .70	7 .62	+ .08
50	7 .23	7 .38	7 .63	7 .63	7 .83	.70	7 .63	7 .68	— .05
11 15	7 .27	7 .47	7 .62	7 .52	7 .82	.70	7 .77	7 .76	+ .01
30	7 .32	7 .47	7 .57	7 .52	7 .82	.70	7 .77	7 .80	— .03
12 0	7 .34	7 .39	7 .54	7 .54	7 .89	.70	7 .89	7 .87	+ .02
30	7 .32	7 .42	7 .52	7 .57	7 .87	.70	7 .87	7 .88	— .01
50	7 .32	7 .42	7 .52	7 .52	7 .92	.70	7 .92	7 .86	+ .06
13 20	7 .39	7 .44	7 .49	7 .49	7 .89	.70	7 .74	7 .80	— .06
45	7 .28	7 .53	7 .48	7 .53	7 .88	37.70	7 .68	7 .72	— .04
Mean Er.±	$0^m.036$	$0^m.034$	$0^m.036$	$0^m.059$	$0^m.030$				$0^m.032$

I have given in full detail the observations of L 5861 taken on one night, because the only arguments for or against the oft-repeated depreciation of eye-estimates worth considering are facts, not opinions.

The observations given, those of July 1, 1896, are in no way outstanding. I have only referred to them here because in another paper dealing with the variation of L 5861 I have selected this night's observation as a good instance of how the mean curve is obtained. On some other nights in July the accordance between the several measures is even more striking.

Is it possible that these measures can be vitiated by mental bias? Not only does the ever changing hour angle change the relative magnitudes, when viewed with the same eyepiece, but each observation with the reversing eyepiece is immediately followed by an observation with a direct vision eyepiece, which completely alters the apparent magnitude of every star under consideration. Each set is different from those that precede and those that follow; similarity in the estimates means error. Then again, between each set of two, four or five observations of other variables are taken; thus an open mind encounters each observation in turn, and complete mental detachment is secured.

As regards bias, accordingly, measurements by Argelander's method can be made as secure as any series obtained photometrically.

The mean error obtained from an application of a common light curve to all the observations of L 5861, viz.,

$$\pm 0^{m}.037$$

is in no way singular.

In the *Astronomical Journal*, No. 327, I have given in detail the observations taken during 1894 of the southern Algol variable, S Velorum.

The average discordance between the observed places and a mean curve computed rigorously from the expression,

$$M = x + \alpha t + \beta t^2 + \gamma t^3 + \delta t^4$$

is for the different nights:

1894 April 1 = ±0^{m}.042 (*Ast. Jour.* No. 327, p. 115)
April 13 = .036
May 1 = .032
May 7 = .044
May 25 = .042
May 31 = .056 Weight ¼
July 23 = .037
July 29 = ±0 .015 Weight ¼
Average error = ±0 .038

The form of the light curve obtained for this variable not only corresponds with that obtained photographically, but it is in strict harmony with the curve obtained from a geometrical consideration of the eclipse of one star by another.

In the *Astronomical Journal*, No. 373, are given in detail the observations secured here of R. S. Sagittarii.

The mean discordance which follows from the application of a single light curve to all the measures is $\pm 0^{m}.036$. And here I may point out that this constant error is also that of the determinations of the magnitudes of the comparison stars used, when reduced to a common standard.

Observations of these three stars have already been published because of their immediate importance; an examination, however, of over 12,000 observations (chiefly of short period variables) not yet published, yields almost identical results. The mean error of sixteen new southern short period variables is

$$\pm 0^{m}.040.$$

Is this constant mean error to be considered entirely fortuitous? Such a contention is out of the question.

This constant value $\pm 0^{m}.04$ is the measure of the accuracy of this method of determining stellar magnitudes; and all other claims to a more consistent gauge, or a more rigorous standard of measurement, or even more trustworthy results, must be related to this value. No other conclusion is tenable or possible.

I take it, therefore, that Professor Pickering's first averment is something more than an unproved statement; it is an unprovable one.

We are naturally led from a consideration of the first statement to the second, viz., that it is impossible to assign absolute values to visual determinations of magnitude. This statement has so often been made, that at last it has become somewhat axiomatic, and this notwithstanding—

(1) That there is more conformity between so-called arbitrary magnitudes determined visually, than between magnitudes determined photometrically. An examination of different uranometria will abundantly prove this.

(2) That photometrical determinations of magnitude are also arbitrary, inasmuch as if we consider the typical relation between photometrical magnitudes, viz.,

$$\frac{L_x}{L_{x+n}} = K^n$$

x and K must be arbitrary.

(3) The natural relation between magnitudes is the visual one, inasmuch as it is the relation which appeals directly to the senses without any intermediate relationship.

(4) The visual standards of reference $6^m.8$ and $9^m.3$ are clearly defined points of reference.

The question however is not an important one in its relation to the physical causes which underlie stellar variation. The same objection, also, could be as reasonably urged against the use of the heliometer for the determination of planetary positions. Like the heliometer, eye-estimates are differential in their principle of operation; but all differential measures may be made absolute by linking them on to one or more positions absolutely determined. In eye-estimates we have at least two such well-defined standard values, $6^m.8$ and $9^m.3$.

These two points have been determined again and again by different observers. They accordingly form the terminal points of our photometric base line. Between these two points a series of measures can be obtained, not one of which will be $0^m.1$ in error. Indeed, if observations be repeated over and over again, as in the case of the comparison stars for L 5861, the average error will be reduced within $0^m.05$.

We have already seen that the average *absolute* errors (Table (3)) for the comparison stars are

A. Z. C. xiv. 505 = $0^m.031$
639 = 0 .036
837 = 0 .046
259 = 0 .051
512 = 0 .039
Mean absolute error = $0^m.041$.

That we call a star just visible to the naked eye $6^m.8$ and a star just visible in a good 1^{in} glass $9^m.3$, on a clear night, at altitude 60°, because these values accord best with the conventional values of Argelander and Gould, does not make the method of eye-estimates one based on arbitrary values, any more than the photometrical determinations of magnitude are arbitrary because $2^m.1$ is taken as the magnitude of Polaris, and 2.512 as the value of the light ratio.

The one method, in application and in results, is as absolute as the other.

"In any careful study of the causes of the variation of different stars, photometrical measurements are almost indispensable," is Professor Pickering's third contention. It is the second sentence in Professor Pickering's interesting article, but I have considered it here because what has gone before would be sufficient refutation of the statement if there were not another and more direct argument against its acceptance. The "careful study of the variation of different stars" by the "indispensable" photometric method has still to be made. All the knowledge we have of the physical conditions of the orbital movement of such stars as Algol,[1] Z Herculis, R. S. Sagittarii, and S Velorum we owe to the simple method of eye-estimates by sequences.

And it will always be so. The mean error of a single observation by eye-estimates must be, from the very nature of things, less than the mean error of a single photometric measurement. The photometric measurement is fundamentally an eye-estimate, and must of necessity be liable to every source and possibility and amount of error that influences eye-estimates; and to this must be added the peculiar errors that are incidental alone to such indirect modes of measurement as all photometrical methods are. It is true that eye-estimates, when finally reduced, give only relative differences in magnitude, and that they do not indicate in any way the amount of light, while in investigations, dealing with the causes of stellar variation we must obtain the changes in the amount of light, not in the apparent magnitude. Such a transposition can be readily effected without any reference to photometrical measurements.

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[1] I do not here deal with spectroscopic results. These, of course, lie outside the range of the present paper.

I have elsewhere instanced one important and simple method, viz., superposition.

In this case

$$L_x + L_{x-n} = L_{x-m}$$

yields the identity

$$1 + K^n = K^m.$$

There is another method, equally simple, by which light grades may be reduced to light ratios. We have already instanced the precision with which absolute values can be assigned to magnitudes between $6^m.8$ and $9^m.3$. Let now a series of object glasses,[1] all less than 1^{in} be selected, and with these several object glasses let the limit of vision for different apertures between $0^{in}.3$ and $1^{in}.0$ be determined from the stars whose magnitudes have already been estimated with the greatest care. An investigation of this determination will yield data by which any so-called "arbitrary" magnitudes may be reduced to actual light values.

It is unnecessary to enter into the matter further. Many determinations similar to that just referred to have been undertaken, but they have been somewhat feeble in intention, the need for refined exactness not being then very pressing. The need is now imperative, if only as a refutation of the charge of insufficiency against eye-estimates.

The preceding paper does not bear within it any imputation against the accuracy of photometrical methods of research. I am willing to accept all that its able exponent, Professor Pickering, claims for it, *per se*. This paper also is not an apology or a justification for the method of eye-estimates. It needs not the former, and the records of variable star work during the past fifty years is surely justification enough. But this paper is a protest against the recurrent statements, again and again refuted, that eye-estimates are more inaccurate and less valuable than those made by any of the photometers at present in use.

LOVEDALE, S. Africa,
July 1896.

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[1] Different apertures are not as valuable as different object glasses.

ON THE LEVEL OF SUN-SPOTS.[1]

By EDWIN B. FROST.

IN spite of the large number of solar theories now awaiting scientific acceptance, our actual knowledge regarding the Sun is decidedly limited, and the mass of statistics regarding its surface that has accumulated in recent years has thus far not greatly clarified our views as to the nature, and still less as to the causes, of the solar phenomena.

I desire for a few moments your attention in considering our present knowledge as to the elevation of Sun-spots, and I will state at the outset that in the light of recent observations I shall venture to call in question the venerable theory that Sun-spots are depressions in the solar photosphere.

In speaking of levels we must proceed from some accepted plane of reference; and the most natural plane, or surface of reference, would be the solar photosphere. Here we are abruptly confronted by the theory of Schmidt, elaborated in a convenient form by Knopf,[2] according to which the photosphere is merely an optical illusion, produced by circular refraction in the Sun itself, supposed to be a globe of glowing gas without a condensed stratum. Prominences, faculæ, spots, and the granulation are explained as effects of anomalous refractions due to local changes of density somewhere within the gas ball.

This theory, worked out as it is by careful mathematical reasoning, deserves and has received respectful consideration. Nevertheless, in view of the physical improbability of Schmidt's primary assumption that in its outer portions the gaseous mass maintains its state without condensation, the physicist will feel obliged to reject the theory, which also suffers from the fundamental defect of failing to account for the solar spectrum on the accepted principles of physics. Moreover, any one who has with some continuousness studied the phenomena of the solar surface must affirm that he has observed realities, not illusions. The perspective effects on prominences as they pass around the limb, the motion and permanence of spots, the displacements of spectral lines on the approaching and receding limbs, and in fact all the phenomena concerned in the solar rotation, are distinctly contradictory to Schmidt's theory. In dismissing it from further consideration, however, we shall take with us the important inference that refraction within and on the Sun itself may modify in some considerable degree the phenomena we observe.

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[1] A paper read at the meeting of the American Association for the Advancement of Science, August 1896.

[2] Jena, 1893.

In illustrating an application of this inference we may digress slightly by citing a theory of spots and faculæ suggested by James Renton in a recent number of *Nature*,[1] received while this paper was being written. He advances the idea that a spot and the surrounding faculæ are due to an anticyclonic area (of descending currents) over the photosphere. In consequence of the convexity of the successive surfaces of equal density in the solar atmosphere, the radiation from the photosphere centrally under the anticyclonic area will be divergingly refracted so that it will appear to emanate from a greater area than is actually the case. Hence there will result a deficiency in the intensity of the radiation as compared with that from a portion of the photosphere over which the atmospheric pressure is normal and the surfaces of equal density are concentric with the photosphere. At the outer edge of the high pressure area Renton considers that the refraction would cause the rays to converge, compressing into a smaller area of the apparent disk the radiation from a ring of photospheric surface around the "spot," with consequent increase in surface intensity, thereby producing the faculæ. While observers will probably agree that refraction must be much less effective than the general absorption by the affected atmospheric area, Renton's suggestion is nevertheless important as recognizing in a rational way the possible results of refraction.

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[1] *Nature*, 54, 317, Aug. 6, 1896

Reverting, then, from our digression, we shall adhere to the view that the photosphere does exist as a condensed stratum of some stability, granulated perhaps by the friction of overlying atmospheric currents, and we shall employ it as our surface of reference.

In now considering the elevation of Sun-spots with respect to the photosphere we shall be able to avail ourselves of four different lines of evidence: (1) direct observation; (2) the solar rotation; (3) thermal absorption; (4) spectroscopic observations.

The belief that Sun-spots are depressions in the photosphere dates back to the last century, when Wilson of Glasgow asserted this to be the necessary conclusion from observed effects of perspective. Probably most observers have at some time noted cases where the penumbra *appeared* foreshortened as the spot rounded the limb. The writer has been led to reëxamine the question of the elevation of spots from the evidence of thermal absorption, and in a paper[1] before this Section at the meeting in 1892 ventured to account for certain measurements on spot radiation on the ground that they "lie in a higher stratum than the photosphere." Within the past two years a large amount of direct observational material has been adduced by assiduous observers to show the incorrectness of the Wilsonian doctrine.

At the meeting of the Royal Astronomical Society in December 1894, F. Howlett presented to the Society[2] several volumes of solar drawings which in all represented the devotion of thirty-five years to the study of the Sun's surface, chiefly with a view to determining this very question: are Sun-spots elevations or depressions with respect to the photosphere? Howlett's conclusion is that his direct visual evidence decidedly refutes the depression theory. Indeed, in the rare cases where the perspective effect seemed to displace the (supposed) central umbra towards the center of the disk, the evidence was by no means necessarily in support of Wilson's view; for it was not proven that the umbra was central when the spot was further from the limb, and hence not subject to distortion by perspective. Moreover, Howlett found his visual observations to be corroborated by an examination he was permitted to make of the Greenwich solar photographs. He asserts that "instead of the penumbra of spots possessing *shelving sides*, sloping down towards the umbra, it (the penumbra) presents a *convex* surface; that is to say, a curve conformable to the general contour of the solar orb." Howlett also cites the names of Spoerer, Perry, Ranyard, and Whipple of Kew, as experienced observers who were satisfied of the incorrectness of the depression theory.

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[1] *A. N.*, 130, 129–146, 1892.

[2] *M. N.*, 55, 73–76, 1894.

In the *Monthly Notices*[1] for April 1895, Sidgreaves brings the data obtained in the long series of visual observations at Stonyhurst to the support of Howlett's position. Of 187 single tests—of spots suitably situated for use for the purpose—he finds 140 opposed to Wilson's depression theory, and but 47 which might seem to confirm it, although he adds that at Wilson's own "valuation of their testimony, nearly all the 47 witnesses will go out of court." Individual spots are cited by Sidgreaves in which the visual and photographic evidence is convincing as to the elevated nature of the spots. Both Howlett and Sidgreaves refer to the impossibility that notches could be made in the edge of the disk by any ordinary spots, if they are depressions; while notches might occur as spots approached the limb, as was contended by Lalande, Kirchhoff and others, if spots are elevated masses of gas.

Per contra, however, it should be stated that the careful study of a large number of photographs, made some thirty years ago by De la Rue, Loewy, and Stewart, led them to adopt Wilson's view; and the measurements of Secchi and others, although difficult, were accepted as indicating a depression of the umbra of a few thousand miles below the photosphere.

In summing up this conflicting evidence from direct observation, I believe it must be admitted that the question of elevation of spots is at least an open one, and deserving careful consideration from students of solar physics.

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[1] *M. N.*, 55, 282–287, 1896.

We next examine the evidence afforded by the rotation of the Sun, as determined by the motions of the spots, faculæ, and photosphere itself, availing ourselves for this purpose of the valuable results recently published[1] by Stratonoff, in combination with the classical researches of Dunér[2] and Spoerer. Stratonoff had for an object the study of the motions of the faculæ, and he reaches the satisfying result that they exhibit an equatorial acceleration as do spots. I use the word satisfying, since the researches of Wilsing and of Bélopolsky were at variance on this point, as the measurements of the former failed to indicate an acceleration. It is incidentally that Stratonoff brings out the for us important fact that the order of the velocity of rotation is faculæ, spots, surface.

The motion of the surface was obtained with great precision by Dunér from measurement of the shifts (by Doppler's principle) of certain lines of the spectrum of the approaching and receding limbs of the Sun. Hence when we say "surface" we in fact refer to the level at which these absorption lines are produced. These lines were due to iron, hence we further limit our statement to the level of absorption of the stratum of iron vapor producing these lines ($\lambda 6301.72$, $\lambda 6302.72$), a stratum that may be reasonably supposed to lie very near the actual photospheric surface.

The results of Stratonoff, which have more recently been confirmed by Wolfer of Zurich in a memoir just received,[3] are more important for our question than at first might appear, since the faculæ have always been admitted to be at a higher level than the photosphere. Now we find that they share the peculiar law of rotation of the spots and surface (iron vapor level), and with numerical values next greater than those obtained for the spots, whose rotation was in turn faster than that of the "surface." Hence it is a logical inference that the level of the spots is intermediate between that of faculæ and surface.[1]

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[1] *A. N.*, 140, 113–119, 1896.

[2] *Sur la Rotation du Soleil*, Upsala, 1891.

[3] "Zur Bestimmung der Rotationszeit der Sonne." Separatabdruck aus der *Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich*, XLI., 1896.

The evidence from thermal absorption that Sun-spots are situated above rather than below the level of the photosphere is perhaps the strongest that can be at present adduced. It may be stated quite simply. Measurements by Langley, by the writer, and by W. E. Wilson have furnished quite accurate tables[2] showing the decrease in the intensity of the thermal radiation at different distances from the center of the Sun's disk to the limb. The law of this absorption as found by experiment agrees quite satisfactorily with the theoretical law of Laplace after a suitable correction to make it accord with modern physical views.

The three observers mentioned have also measured the intensity of the thermal radiation from Sun-spots as compared with that from equal areas of adjacent photosphere. Now when a spot passes by the Sun's rotation from a point near the center of the disk toward the limb, it is found that the relative intensity of the spot increases. This might mean either that the radiation from the spot was greater, or that from the neighboring photosphere was less. But with our table showing the increase of absorption over the photosphere from the center of the disk outward, we can readily reduce our ratio to what it would be if the comparison area of photosphere were constantly at the center of the disk. On doing this we at once see that the thermal absorption over spots does not increase as we approach the limb in nearly the degree that is the case with the photosphere. The reasonable inference from this is that the spots are at a higher level than the photosphere, and hence less subject to the absorption of the Sun's atmosphere.

Still further, Langley and the writer have found instances in which the measured radiation from spots very near the limb *exceeded* that from the neighboring photosphere. As compared with an area of photosphere near the center of the disk, however, the radiation of the spot is always the less; as would be expected, unless we were to adopt the view, improbable in itself and contrary to these observations, that with the solar atmosphere removed Sun-spots would be actually more radiant than an equal photospheric area.[1] We are therefore again led to the conclusion that the level of spots is higher than that of the photosphere, so that less absorption occurs over the spots, making them in some cases appear to radiate more than neighboring areas of photosphere.

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[1] Since this paper was read, the August number of this JOURNAL has arrived, in which (p. 105) Wilczynski draws the same inference—"*that the spots are at a higher level than the photosphere*"— from Stratonoff's results.

[2] Collected on p. 302 of the new (1895) edition of Young's *The Sun*.

Thus far the spectroscope has not been called in witness in the case before us. A testimony from it contradictory to the view whose merits we are stating might well be considered fatal to that view; a favorable testimony would not be as convincing as an unfavorable one would be damaging.

Now it would appear that in fact the spectroscopic evidence is not competent to decide the question. The Wilsonian doctrine was accepted long before the spectrum of a Sun-spot had been examined; and when such examination was made, no contradiction was found. The spectrum of a spot shows firstly a general absorption, and secondly a selective absorption, not produced by smoke or solid particles, but, as has been pointed out by Young, Dunér, and others, by gases of less radiating power than the surface behind them. Large numbers of dark lines are broadened where the slit crosses a spot, and narrow down as they extend through the penumbra; others are thinned over the umbra; sometimes those of calcium (H and K always), hydrogen, magnesium, and other metals are reversed; perhaps a majority of the lines are wholly unaffected.

To produce these effects it seems to be quite immaterial whether the absorbing masses of vapor are situated entirely above the photosphere or in cavities in it; in either case the white light that is absorbed is by all considered to be due to the photosphere,—from an under stratum of it, according to the depression theory of spots; from its ordinary upper surface, according to the elevation theory. The same spectrum in umbra and penumbra would result from a "convex" mass of gases (say an anticyclone) above the condensed stratum, as from the gases poured into a cavity extending downward partly through that stratum (the photosphere). Arguments might be brought forward tending to show that the conditions in elevated masses of gas would be more favorable for the production of the observed effects, but in our present state of knowledge such reasoning would be based more on theory than on fact, and therefore I prefer to regard the evidence from the spectroscope as at present undecisive.

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[1] It will be noted that in this discussion I have not spoken of relative temperature, a very different thing from relative thermal radiation, the quantity measured in such observations.

The query will probably be raised as to the bearing of the view presented in this paper upon the most prevalent Sun-spot theories; those of Secchi, Faye, Oppolzer. The first is summar, ized by Young as follows:[1] "Secchi believes them to be dense clouds of eruption-products settling down into the photosphere *near*, but not *at*, the point where they were ejected." Evidently the validity of this theory is not affected by the adoption of the view that the spots are gaseous masses above the photosphere, finally in their descent settling down upon it.

Faye's theory is based upon the relative drift of contiguous portions of the photosphere itself, due to the equatorial acceleration of the Sun's rotation. It would seem that the vortices might equally well take place in the gases above the photosphere as in that stratum itself. Certainly his view that the vorticular disturbance of the solar atmosphere propagates itself downwards conforms better to the elevation theory.

The Sun-spot theory of Egon von Oppolzer, based upon meteorological analogies, is in many respects a very promising one. To the writer no theory seems satisfactory which does not take into consideration these analogies in the terrestrial atmosphere. With the descent of masses of gas, under solar gravitation, their temperature must rise, at certain levels perhaps being comparable with the photosphere in radiance, even if adiabatic conditions are but imperfectly realized, and this may possibly account for the reversed lines of calcium over spots. Oppolzer's may be called an anticyclone theory of Sun spots, but its validity seems in no wise diminished if we consider that the descending currents do not penetrate the photosphere, but produce their absorption and run their course entirely above the photosphere.

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[1] *The Sun*, 1895, p. 182.

The considerations that have been brought forward in this paper may seem to many to be insufficient for abandoning the doctrine of Wilson, but my purpose will be accomplished if observers shall give to this still unsettled question the attention that it fairly deserves.

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RÉSUMÉ OF SOLAR OBSERVATIONS MADE AT THE ASTROPHYSICAL OBSERVATORY OF CATANIA IN 1895.

By A. MASCARI.

DURING the year it was possible to utilize 331 days for observations of Sun-spots, 223 for faculæ and 224 for prominences. The methods of observation and the instruments employed have already been described in this JOURNAL.[1]

Table III. shows that the frequency of groups containing both pores and spots, and those containing only pores, diminished from the first to the third quarter. There was a slight increase in the last quarter, but the whole year shows a diminution when compared with 1894. This diminution was found also for the spots considered separately, and for the general frequency of the year, although the monthly results show certain irregularities, with the highest maximum of frequency for the entire year in October and the lowest minimum in November, when for three consecutive days we observed the Sun without spots, on one of these days even pores being absent.

The phenomenon of spots, considered by hemispheres, has shown a constant increase of spots and pores in the northern hemisphere, distributed in a smaller number of groups. The results are as follows:

	First Half		Second Half	
	Northern Hemisphere	Southern Hemisphere	Northern Hemisphere	Southern Hemisphere
Group of spots and pores..	2.75	2.95	2.38	2.60
Spots	4.91	3.77	4.34	3.49
Pores	16.6	14.4	17.1	9.9

The distribution in 10° zones of the spots and pores, for which the latitude has been calculated (Table II.) shows that

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[1] *Ap. J.* 2, 119.

TABLE I.

Day of month	January					February					March				
	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences
1	..	..	..	..	..	8	15	45	..	2	8	10	20	..	4
2	9	5	22	..	..	8	11	63	10	4	..	..	..	..	..
3	8	4	23	..	1	8	15	19	..	..	6	7	33	..	..
4	..	..	..	..	..	7	10	55	10	2	7	9	26	7	3
5	6	11	34	..	..	7	9	41	..	2	7	10	9	9	3
6	5	7	58	..	4	4	5	31	7	..	5	8	18	12	2
7	7	7	40	5	4	4	8	30	13	..	4	8	25	..	3
8	4	6	46	10	1	4	9	13	..	4	4	8	24	..	2
9	6	6	44	8	1	6	5	28	11	3	4	8	35	9	4
10	6	8	39	8	0	6	4	22	..	3	6	8	49	14	2
11	7	8	59	10	..	4	5	31	11	9	..	..	..	..	..
12	4	7	33	11	..	..	..	..	..	..	..	..	..	..	..
13	3	4	31	9	1	4	6	16	..	..	5	10	39	..	..
14	3	2	18	6	3	6	5	11	10	3	4	11	26	6	4
15	5	2	15	11	4	..	..	..	..	..	5	8	7	..	..
16	4	1	20	..	..	5	6	29	13	4	..	..	..	..	..
17	3	2	25	11	1	6	6	18	..	..	..	..	..	..	..
18	5	6	21	11	2	7	9	11	..	2	5	9	22	10	4
19	4?	10?	6?	..	..	6	9	10	..	..	4	11	19	12	5
20	4	7	41	14	3	6	5	42	..	2	3	10	29	..	5
21	4	8	56	12	2	..	..	..	..	..	4	12	27	..	3
22	4	6	39	..	..	6	9	28	13	0	4	12	24	..	2
23	6	6	77	..	..	..	..	..	..	..	5	8	19	8	3
24	7	6	52	16	2	10	13	53	..	..	6	7	25	12	5
25	7	7	83	14	1	..	..	..	..	..	5	10	13	..	5
26	8	12	72	13	4	10	12	34	..	..	4	9	13	10	..
27	9	15	52	..	..	10	13	35	..	..	6	8	6?	..	3
28	8	18	83	..	..	10	13	32	8	3	5	8	14	..	..
29	8	19	52	..	..	..	..	..	..	..	4	7	29	12	4
30	10	20	52	..	..	..	..	..	..	..	4	8	31	..	4
31	..	..	..	..	..	..	..	..	..	..	4	9	14	..	..

the most active region in both hemispheres was the zone ±10°±20°, and that no spots were seen in the zones higher than ±40°. The extreme latitudes reached by the spots this year were +32°.0 and −31°.3

The mean latitude of the spots for the different quarters is diminishing, which illustrates the tendency of the phenomenon to seek lower latitudes; calculation gives 14°.5, 14°.3, 13°.6 and 12°.6 for the mean latitude of the spots in successive quarters.

TABLE I.—*Continued.*

Day of month	April					May					June				
	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences
1	3	7?	2?	..	..	6	9	22	..	..	5	7	25	17	1
2	7	9	21	9	4	8	10	27	10	3	6	11	24	15	..
3	6	9	25	7	7	4	5	19	11	..	6	6	35	21	4
4	5	9	19	..	..	3	5	10	12	..	5	5	41	14	3
5	8	7	24	9	9	2	3	21	16	..	6	8	67	16	2
6	6	4	37	11	3	..	..	..	..	..	6	11	58	..	..
7	..	..	..	..	..	..	..	..	..	..	6	8	62	16	3
8	8	3	40	11	3	4	3	13	12	3	6	12	31	17	3
9	7	6	34	9	2	3	2	12	..	..	6	8	51	17	2
10	8	10	27	7	3	4	3	19	13	2	6	10	24	14	4
11	9	12	20	12	5	3	2	7	11	1	5	7	18	11	3
12	8	10	22	8	3	7	6	10	12	2	4	10	10	..	1
13	7	9	33	11	0	5	3	18	14	7	5	9	25	16	1
14	5	5	27	16	..	5	6	27	15	4	5	11	33	18	2
15	5	3	24	11	6	4	4	30	11	4	5	21	44	15	6
16	5	7	19	..	..	3	6	12	..	..	5	16	69	14	3
17	5	9	34	..	2	5	7	20	13	4	4	15	52	14	3
18	3	7	18	12	5	4	7	12	..	4	4	15	34	14	2
19	..	..	..	..	..	5	5	24	10	2	4	9	31	15	2
20	4	8	33	9	1	5	6	33	11	3	4	0	11	15	6
21	5	13	18	..	3	5	8	27	..	4	4	9	38	17	2
22	6	15	27	..	3	5	8	47	13	5	5	10	27	16	3
23	8	12	46	11	0	7	12	44	..	..	5	11	28	11	2
24	6	9	55	..	..	7	18	24	..	..	6	7	45	14	4
25	6	10	36	8	2	..	..	..	..	..	7	7	31	13	2
26	8	14	49	10	2	9	14	39	..	..	5	4	29	..	1
27	7	14	43	..	..	10	13	55	13	5	5	5	21	16	1
28	..	..	..	..	..	9	16	45	13	2	5	8	26	14	3
29	7	18	36	..	..	7	13	28	16	6	7	10	27	13	2
30	6	14	32	..	..	7	10	20	12	3	6	8	34	12	1
31	..	..	..	..	..	8	8	25	14	1	..	..	..	..	..

In the case of the faculæ we see from Table II. that there were present in each solar hemisphere two maxima, almost symmetrically arranged on each side of the equator in the zones ± 10° ± 20° and ± 70° ± 80°, with a secondary mininum in the same zones ± 50° ± 60°, in addition to the two other minima in the zones of the equator and the poles. In comparing these results with those of last year it is seen that the maximum between ± 10° ± 20° remained stationary, as did also the other secondary maximum of the northern hemisphere

TABLE I.—*Continued.*

Day of month	July					August					September				
	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences
1	7	6	36	14	6	5	8	34	9	3	4	4	19	9	4
2	8	7	12	16	7	6	10	36	10	5	5	6	27	10	6
3	5	5	10	..	..	6	14	58	6	7	5	5	15	9	8
4	5	4	20	11	4	7	15	51	..	4	7	4	26	10	8
5	5	4	6	..	6	6	17	59	..	..	6	5	17	8	6
6	5	2	21	10	5	7	20	115	8	3	6	11	22	9	8
7	6	7	12	9	2	6?	17?	31?	..	4	5	9	15	12	5
8	7	9	39	11	1	7	20	60	9	3	5	7	19	..	5
9	9	11	54	..	1	6	12	111	10	4	5	5	34	9	3
10	7	10	33	14	3	7	13	84	8	5	5	4	7	13	4
11	7	13	45	13	0	6	15	78	10	3	3	3	4	10	1
12	4	10	19	17	2	6	12	74	9	3	3	2	6	10	5
13	6	14	38	..	1	6	10	38	11	3	5	3	27	10	3
14	7	11	36	15	5	6	8	23	10	1	5	7	33	13	3
15	6	9	28	8	6	4	4	15	8	4	6	5	46	11	2
16	5	6	10	15	4	5	7	17	8	9	6	4	36	..	5
17	5	4	22	10	10	5	7	35	12	2	3	3	15	8	4
18	5	4	9	11	4	3	8	16	9	8	3	3	7	11	..
19	2	1	7	6	6	3	10	19	..	6	2	3	2	..	..
20	3	1	6	9	4	4	7	31	10	4	4	3	15	10	7
21	2	4	9	9	7	2	5	34	10	7	3	2	21	10	8
22	2	4	3	12	0	2	5	38	11	9	5	2	25	9	3
23	4	3	5	12	5	3	4	21	7	6	3	6	5	..	4
24	..	..	..	..	..	5	9	21	8	6	5	6	9	8	4
25	1	1	0	8	6	6	9	18	11	3	7	5	13	11	2
26	1	1	1	10	6	4	6	6	12	1	8	8	14	8	4
27	4	2	14	6	3	..	..	..	..	..	9	11	30	8	4
28	3	2	23	..	3	..	..	..	..	..	7	10	37	7	2
29	3	4	15	11	5	3	4	16	10	4	6	12	40	..	4
30	2	3	27	8	5	3	5	8	8	4	7	17	43	12	2
31	3	6	35	8	..	4	4	7	..	3	..	..	..	..	..

in the zone + 70° + 80°. The other secondary maximum of the southern hemisphere, which in 1894 was in the zone — 60° — 70°, has moved to a higher latitude, in the zone — 70° — 80°. The minima which in 1894 were in the northern zone + 60° + 70°, and in the southern zone — 40° — 50°, were in 1895 in + 50° + 60° and — 50° — 60° respectively. The mean frequency of the faculæ was greatest in the northern hemisphere during the first half of the year, and during the second half about equal in each hemisphere. Thus for the entire year the

TABLE I.—*Continued.*

Day of month	October					November					December				
	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences
1	8	17	85	8	3	6	13	66	..	..	3	1	6	8	..
2	7	29	20	..	4	..	..	..	..	..	..	..	..	..	..
3	7	27	70	11	5	6	15	67	..	..	4	3	19	17	6
4	6	24	28	..	1	..	..	..	..	..	3	5	15	12	7
5	5	17	41	..	4	..	..	..	..	..	5	5	17	8	1
6	6	12	66	8	1	3	9	22	10	3	6	8	20	11	3
7	3	12	46	9	2	3	6	37	9	3	6	8	10	..	3
8	3	11	35	5	2	2	2	13	7	2?	7	12	31	..	..
9	3	5	36	14	4	1	1	3	11	3	7	14	24	..	2
10	2	3	2	10	..	0	0	0	12	..	8	10	42	..	3
11	2	3	2	..	1	1	0	4	11	2	9	12	62	11	2
12	6	3	10	13	2	1	0	3	8	4	12	11	81	12	..
13	3?	3?	4?	..	3	2	2	9	13	3	11	12	71	..	..
14	4	3	5	14	5	5	5	18	8	3	9	8	55	..	6
15	4	2	11	10	1	5	7	17	12	5	6	8	25	..	6
16	2	2	8	13	5	..	..	..	..	..	8	10	33	..	..
17	2	2	6	6	4	6	5	24	10	4	8	7	33	..	..
18	..	..	..	..	..	5	3	27	8	1	..	..	..	..	..
19	2	1	6	..	..	6	5	18	8	5	7	7	21	10	..
20	..	..	..	..	..	7	5	13	10	5	7	8	12	12	..
21	4	7	9	..	2	4	4	8	8	3	5	9	45	..	1
22	4	12	2	..	3	..	..	..	..	..	8	14	28	..	5
23	5	15	26	..	..	5	5	1	..	..	7	14	44	..	..
24	5	15	50	12	3	..	..	..	..	..	9	13	43	9	1
25	6	19	21	..	5	6	6	8	13	2	8	11	20	..	..
26	4	16	58	11	..	5	6	0?	..	..	9	10	35	..	..
27	4	16	107	9	5	..	..	..	..	..	7	9	33	9	..
28	4	14	86	..	2	4?	5?	2?	..	7	..	..	..	..	..
29	6	17	70	11	0	4	2	4	13	..	4	6	19	..	1
30	6	15	71	12	2	..	..	..	..	..	3	8	16	14	2
31	7	16	55	..	1?	..	..	..	..	..	4	8	19	13	..

northern hemisphere was the richer in faculæ, the reverse of what was observed in 1894, when the southern hemisphere had the preponderance.

The great differences between our own observations and those of others regarding the number and distribution of the faculæ is due in part to the method of observation and the size of the projected image. We always see the faculæ in all latitudes, but in the higher latitudes the faculæ near the limb are never seen in long trains: they are usually isolated or in small groups.

TABLE II.

	Heliographic Latitude	Spots					Faculæ					Prominences				
		First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Year 1895	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Year 1895	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Year 1895
North	80° to 90°	0	0	0	0	0	8	37	21	20	86	0	0	0	1	1
	70 " 80	0	0	0	0	0	16	38	31	27	112	0	0	0	0	0
	60 " 70	0	0	0	0	0	17	38	30	20	105	0	0	0	0	0
	50 " 60	0	0	0	0	0	14	34	34	20	102	1	6	21	4	32
	40 " 50	0	0	0	0	0	20	41	30	25	116	5	9	70	24	108
	30 " 40	0	1	0	0	1	23	57	43	22	145	13	32	43	20	108
	20 " 30	3	3	5	5	12	26	66	42	49	183	17	30	41	18	106
	10 " 20	23	24	16	20	76	41	81	93	49	264	21	23	22	15	81
	0 " 10	10	9	9	7	38	21	52	33	30	136	15	25	22	11	73
South	0° to 10°	9	7	11	6	31	33	65	46	28	172	13	19	24	17	73
	10 " 20	19	17	20	22	73	44	77	82	50	253	16	13	26	12	67
	20 " 30	10	7	5	2	24	33	55	68	43	199	12	25	29	17	83
	30 " 40	1	1	0	0	2	22	44	44	22	132	18	9	33	19	79
	40 " 50	0	0	0	0	0	16	23	32	13	84	10	8	27	16	61
	50 " 60	0	0	0	0	0	8	25	17	15	65	6	1	5	0	12
	60 " 70	0	0	0	0	0	24	24	29	11	88	0	0	0	0	0
	70 " 80	0	0	0	0	0	20	43	38	28	129	0	0	0	0	0
	80 " 90	0	0	0	0	0	10	28	29	21	88	0	0	1	0	1

During the year the Sun was observed here on six days without prominences higher than 30″. Table III. shows that during the first quarter the frequency of the prominences was nearly equal in the two hemispheres, though during the remainder of the year it was greatest in the northern hemisphere. Taken as a whole there was a slight and increasing activity of the prominences in the first three quarters, although in comparing these results with those of 1894 it is evident that the frequency of the prominences continued to diminish in 1895. Their distribution in 10° zones of latitude shows the almost complete absence of the phenomenon in high latitudes, the minimum in the equatorial zones and the most marked activity in the northern zone + 30° + 50° and in the southern zone − 20° − 30°.

The following conclusions may be drawn from our observations in 1895 :

TABLE III.

1895	Mean Frequency								
	Of groups of spots and pores	Of spots	Of pores	Of prominences			Of faculæ		
				In northern hemisphere	In southern hemisphere	In both hemispheres	In northern hemisphere	In southern hemisphere	In both hemispheres
January	5.83	7.86	42.6	0.75	1.37	2.12	5.12	5.44	10.56
February	6.57	8.74	30.3	1.71	1.36	3.07	5.00	5.60	10.60
March..........	4.92	9.00	22.9	1.80	1.70	3.50	4.50	5.58	10.08
April...........	6.22	9.37	29.7	2.26	1.05	3.32	4.82	5.24	10.06
May	5.50	7.57	24.6	1.84	1.58	3.42	6.80	5.80	12.60
June	5.23	9.43	34.8	1.68	0.89	2.57	8.37	6.63	15.00
July	4.63	5.60	19.8	2.64	1.54	4.18	5.36	5.56	10.92
August.........	4.90	9.69	35.3	2.82	1.57	4.39	4.46	4.88	9.33
September......	4.93	5.83	20.5	2.36	2.07	4.43	4.64	5.16	9.80
October	4.48	11.66	35.7	1.56	1.24	2.80	5.59	4.76	10.35
November......	3.95	4.82	16.5	1.63	1.81	3.44	5.12	4.94	10.06
December	6.48	8.59	30.0	1.87	1.40	3.27	6.15	5.08	11.23
First Quarter ...	5.74	8.51	32.3	1.44	1.50	2.94	4.89	5.53	10.42
Second Quarter .	5.64	8.80	29.8	1.89	1.14	3.03	6.94	6.00	12.94
Third Quarter...	4.82	7.01	25.1	2.61	1.73	4.33	4.82	5.20	10.03
Fourth Quarter..	5.06	8.66	28.3	1.66	1.45	3.11	5.57	4.91	10.49
Year...........	5.30	8.22	28.8	1.99	1.47	3.46	5.60	5.43	11.03

(1) The Sun has exhibited a further diminution in the phenomena of spots and prominences as compared with the year 1894.

(2) The maximum activity of the spots and the primary maximum of the faculæ were in the same zone of latitude ± 10° ± 20°.

(3) The double maximum in each hemisphere of the faculæ, observed in 1894, has been repeated this year.

(4) The activity of all the phenomena, spots, faculæ and prominences, was greater in the northern than in the southern hemisphere.

(5) The discordance noted in 1894 between the distribution in latitude of faculæ and prominences was observed again in 1895.

RESEARCHES ON THE ARC SPECTRA OF THE METALS. II. THE SPECTRUM OF TITANIUM. II.[1]

By B. HASSELBERG.

7. After this discussion I give in the following table the results of the determinations of wave-lengths in the titanium spectrum. As in the case of the similar table for chromium, the successive columns contain the wave-lengths of the titanium lines; the standard lines in the solar spectrum which were used as reference lines, taken from Rowland's catalogue;[2] the estimated intensities of the titanium and solar lines, on a scale of 1:6; and the remarks which were made in the course of the investigation. The last column contains the measurements of Thalén, reduced to Rowland's scale.[3]

λ	R.-Å.	λ	R.-Å.	λ	R.-Å.
390–400	0.85	460–470	0.88	530–540	1.25
400–410	0.73	470–480	0.84	540–550	1.30
410–420	0.56	480–490	0.90	550–560	1.43
420–430	0.63	490–500	0.80	560–570	1.28
430–440	0.80	500–510	0.96	570–580	1.17
440–450	0.85	510–520	1.11	580–590	1.22
450–460	0.95	520–530	1.09	590–600	1.32

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[1] Continued from page 134. With three Plates.

[2] *A. and A.*, 1893.

[3] The reduction factors are given in the following table, obtained by comparing a large number of iron lines (about 100) according to the measures of Kayser and Runge, and of Thalén. Each difference is the mean of from four to six individual differences within each division of 100 tenth-meters of the spectrum. The smaller variations of the figures are of little importance here, where it is only a question of the nearest tenth of a tenth-meter.

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
3477.33		2.3	2		
——	3478.00				
79.07		1.2	—		
80.67		2+	1		
81.83		1	—		
85.84		1.2	1		
89.90		1.2	2.3	⊙ line probably a close double. { Companion toward R=Ti } K.—R. { " " V=Fe } 89.81	
91.20		3	3	very sharp.	
——	3491.47				
93.44		1	1		
95.88		2	2.3		
99.24		2+	1		
3500.48		1.2	2		
05.02		3	2		
06.76		2	2	⊙ line close double K.-R.: 06.66 } companion toward R, Ti. " " V, Fe.	
07.55		1.2	1.2		
10.98		3	2	very sharp.	
11.74		1	1		
12.23		2	1	very diffuse and broad, Ti?	
16.97		1.2	1		
——	3518.48				
20 15		1.2	2.3	diffuse.	
20.39		2	2	sharp.	
24.37		2	2		
25.28		1.2	1		
26.18		1.2	2.3	also a weak Fe line.	
27.62		1.2	—		
30.53		3	2	very diffuse; in Fe also an insignificant line.	
35.56		2.3	2		
——	3540.27				
42.69		1.2	1.2		
45.11		1	1		
47.15		2.3	1		
56.32		1.2	?	diffuse.	
58.66		2	3	also a strong Fe line.	
61.72		1.2	1.2		
——	3564.68				
66.16		1.2	1.2		
73.85		2	2.3	⊙ line double { 73.85 Ti 74.05 Fe } K.-R.: 74.06.	
74.38		2	1.2		
76.00		1	1		
78.40		1.2	?		
80.40		1.2	1		
——	3583.48				
94.13		1	1		
96.17		2.3	2		

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
3598.87		2.3	1.2		
99.25		2.3	1.2		
3601.31		1	1		
01.52		1	1		
03.98		1.2	2	⊙ line close triple.	
04.39		1.2	1.2	very sharp, ⊙ line double $\left\{\begin{array}{l}04.40\text{ Ti}\\ .50\end{array}\right.$	
05.46		2	2.3	very sharp.	
06.18		1—	?	probably a weak ⊙ line.	
07.26		2	1	diffuse.	
09.72		1+	—		
10.29		3	3	Ti appears to be a little to one side of the ⊙ line.	
——	3612.21				
12.40		1.2	—	diffuse.	
13.89		2	?	at the edge of the ⊙ line 13.95.	
14.35		2	—	diffuse.	
20.15		1	1		
21.37		2	2	diffuse; ⊙ line double $\left\{\begin{array}{l}21.20\\ .37\end{array}\right.$	
23.25		2	—	diffuse; close to 23.40 (Fe).	
24.97		2	2	very sharp; ⊙ line double $\left\{\begin{array}{l}24.87\text{ Ni}\\ 25.00\text{ Ti, Fe}\end{array}\right.$ K.-R.: 25.01.	
26.22		1.2	1	very sharp; ⊙ line double $\left\{\begin{array}{l}26.22\\ .30\end{array}\right.$	
33.60		2	1		
35.33		2	2		
35.61		4.5	2	very diffuse.	
36.05		1	1		
38.10		2	—		
——	3640.53				
41.48		2.3	2	very sharp.	
42.82		5	2.3	very diffuse; ⊙ line double $\left\{\begin{array}{l}42.82\text{ Ti}\\ .92\end{array}\right.$	
44.87		2	2	⊙ line close double $\left\{\begin{array}{l}44.87\text{ Ti}\\ .95\end{array}\right.$	
46.32		2.3	1.2	very sharp.	
53.61		5	2	very diffuse.	
54.72		3	2	⊙ line close double $\left\{\begin{array}{l}54.72\\ .80\end{array}\right.$	
58.22		3.4	2.3	⊙ line close double $\left\{\begin{array}{l}58.20\\ .25\end{array}\right.$	
——	3658.68				
59.91		2.3	2.3	very sharp.	
60.75		3	1.2		
62.37		2.3	2.3		
63.82		1	1	⊙ line distinct; not in R.	
66.71		1	1.2		
69.08		2.3	2	⊙ line close double. Separation impossible.	
71.82		3	1.2		

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
3677.90		1	—		
79.88		2	1	diffuse.	
81.38		1.2	1.2		
——	3684.25				
85.30		4	3	diffuse.	
86.10		2	—	not coincident with 86.15 (Fe). K.-R.: 86.16.	
87.48		2	?	at edge of strong ⊙ line 87.63, K.-R.: 87.64.	
88.19		1	1		
90.04		3	1.2		
92.35		2	—	diffuse; Ti?	
94.58		2.3	1		
——	3695.19				
97.05		1	1		
98.33		1.2	—		
3700.22		1.2	—		
02.42		2	2	coincidence not certain.	
03.13		1	—		
04.42		2	1.2	⊙ line double { 04.42 .50	
04.84		1	1.2		
06.37		1.2	2		
07.68		1.2	2	⊙ line double. With which companion?	
08.83		1.2	—		
10.10		2	1.2		
——	3716.57				
17.53		1.2	2		
21.75		2	2	⊙ line belongs to a group of 5 close lines	
22.70		2.3	4	also in Fe a line of medium strength.	
24.70		2.3	2		
25.28		2.3	2		
29.92		3.4	2.3		
33.96		1+	1		
35.84		1.2	1		
39.17		1.2	—		
41.19		3	2		
41.78		2	2	sharp; ⊙ has { 41.65 .78	
——	3747.09				
48.26		2	?		
53.00		3.4	2		
53.75		2.3	2.3	also an Fe line of medium strength.	
57.82		2	2	very sharp.	
59.42		3.4	3		
61.46		3.4	3	⊙ line probably double; coincidence with the component toward violet.	
62.01		1	2		
66.60		1	1		
71.80		2.3	1.2		
——	3770.12				
76.20		1	1.2		

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
3782.26		1.2	1.2		
86.20		2.3	1	⊙ has a triple { 86.12 Fe .20 Ti .34 Fe K.-R.: { 86.14 .37	
86.44		1.2	1.2		
89.46		2	?		
——	3794.02				
96.06		2	1		
98.47		1.2	1	sharp.	
3801.25		1.2	1	very sharp.	
01.73		1	1		
05.25		1	—		
05.64		1	1		
06.19		1	—		
06.60		1	1		
07.37		1	—		
07.93		1	—		
11.56		1	1		
13.42		1.2	1	} ⊙ triple { 13.42 .54 .65	
13.54		1.2	2		
14.72		2	2	⊙ double { 14.60 .72 } Fe, Ti K.-R.: 14.73	
15.01		1.2	1	⊙ line companion to 14.90.	
17.78		2	2	⊙ line probably double { 17.78 .90	
18.38		2	1.2	⊙ line double { 18.40 .50	
——	3821.32				
21.86		1	1.2	sharp } ⊙ has a triple { 21.86 Ti 22.06 Fe 22.16 Ti	
22.16		2.3	1.2		
23.03		1	1.2		
27.12		1.2	1		
27.61		1	?		
27.80		1	?		
28.16		1.2	1	in the shadow of the strong ⊙ line 27.95 (Fe).	
28.31		2	2		
29.87		1.2	?	falls on a strong band of ⊙.	
33.33		2	1	sharp.	
33.80		2	1	sharp.	
34.06		1.2	?	does not appear to coincide with ⊙ line 34.10.	
36.22		1.2	2	sharp.	
36.90		2	1.2		
40.48		1	—		
40.90		1	1		
41.79		1	—		

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
3842.77		1	—	does not coincide with the ⊙ line 42.82.	
——	3843.40				
45.28		1.2	1.2		
46.57		2	2	also in Fe.	
48.48		1.2	1.2	very sharp.	
53.18		2.3	1	diffuse.	
53.87		2.3	1	diffuse.	
55.99		1.2	2		
58.04		1.2	1.2		
58.26		2.3	1.2	diffuse.	
60.61		1.2	1		
61.25		2	?	between the ⊙ lines $\left\{\begin{matrix}61.20\\ .30\end{matrix}\right.$	
61.89		1.2	1.2	diffuse.	
62.98		2.3	1	diffuse.	
64.66		1	1.2		
66.17		1	2		
66.60		3	1.2	diffuse.	
67.92		2	1	diffuse; coincidence not absolutely certain.	
68.56		2.3	1.2	diffuse.	
69.13		1	—		
69.47		2.3	—	diffuse.	
69.75		1.2	2.3	⊙ line distinct, sharp, probably double, also a line in Fe.	
70.28		1.2	2		
73.40		2.3	—	diffuse; at edge of ⊙ line 73.25 (Co, Ni).	
74.32		2	?	falls in the shading of 74.10.	
——	3875.23				
75.44		3	2	diffuse; ⊙ line double. $\left\{\begin{matrix}75.45\\ .55\end{matrix}\right\}$ coincidence not quite certain.	
77.75		1.2	—	diffuse.	
81.85		1.2	2.3	⊙ line appears triple, the Ti line lies on the red edge.	
82.28		3	2.3	diffuse.	
82.49		2.3	2.3	diffuse.	
83.02		3.4	2	diffuse.	
88.20		2	1	diffuse; between two bismuth lines $\left\{\begin{matrix}88.05\\ .34\end{matrix}\right.$	
90.12		2	1.2	sharp; ⊙ line double $\left\{\begin{matrix}90.06\\ .12\end{matrix}\right.$	
95.42		3.4	1	coincidence uncertain.	
——	3897.60				
98.68		2	1	very sharp; ⊙ has $\left\{\begin{matrix}98.58\\ .68\end{matrix}\right.$	
3900.68		2.3	3	also an unimportant Fe line.	
01.13		2.3	1.2		
04.95		3.4	2.3		
11.34		2	1	diffuse.	
13.58		2.3	2.3		
14.45		2.3	2		
14.86		1.2	1	sharp.	

Titanium λ	R.	i		Remarks	Thalén
		Ti	☉		
3916.00		1.2	?		
16.27		1.2	—		
19.95		1.2	1		
21.56		2	1.2		
——	3924.67				
24.67		2.3	2		
26.48		2.3	1		
30.02		2.3	1.2		
34.37		1.2	?		
38.18		1	1		
——	3942.55				
47.90		3	1.2	☉ line close double $\left\{\begin{array}{l}47.80\\ .90\end{array}\right.$	
48.80		3.4	1.2	☉ has a triple $\left\{\begin{array}{l}48.80\ \text{Ti}\\ .90\ \text{Fe}\\ 49.00\end{array}\right.$	
56.45		3.4	2	☉ has a distinct group $\left\{\begin{array}{l}56.45\ \text{Ti}\\ \left.\begin{array}{l}.55\\ .75\\ 57.10\end{array}\right\}\text{Fe}\end{array}\right.$	
58.33		3.4	2		
62.98		2.3	1.2	very sharp.	
64.40		2.3	2	very sharp.	
——	3971.48				
81.91		3.4	2	also in Fe an insignificant line.	
82.62		2.3	1.2	☉ line close double $\left\{\begin{array}{l}82.62\\ .70\end{array}\right.$	
84.48		1.2	—		
85.57		1.2	—	diffuse.	
85.76		1.2	—	diffuse.	
89.92		4	2	☉ line close double $\left\{\begin{array}{l}89.92\ \text{Ti}\\ 90.00\ \text{Fe}\end{array}\right.$ K.-R.: 90.01	
94.84		1.2	—	diffuse.	
98.77		4	2.3		
99.53		1.2	—	diffuse.	
4002.63		2	—	diffuse.	
——	4003.91				
03.99		2	—	diffuse.	
06.14		1.2	—	diffuse.	
07.38		1.2	—	diffuse.	
08.20		2	—	diffuse.	
09.06		3	2		
09.80		2	—	between the ☉ lines 09.70 and 09.87 (Fe).	
12.55		1.2	2	sharp.	
13.72		2.3	—	diffuse.	
15.56		2	—	diffuse.	
16.44		1.2	—	diffuse.	
17.13		1	—		
17.93		2	—		
21.98		2.3	—	diffuse.	

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
4024.71		3	2		
25.26		1	2		
26.64		2.3	—	diffuse.	
27.66		1.2	—		
28.48		1.2	2		
——	4029.79				
30.60		2.3	—	diffuse.	
34.05		1.2	1	⊙ line exceedingly weak; not in R.	
35.05		1.2	1	group of exceedingly weak ⊙ lines not in R.	
35.98		2	—		
——	4048.88				
53.96		1.2	1.2		
55.18		2.3	2	also a weak Fe line.	
57.76		1.2	?	diffuse; in the shadow of 57.60.	
58.28		2	?	diffuse; ⊙ has 58.37 (Fe).	
60.42		2.3	1.2		
——	4062.60				
64 36		2	1	very sharp.	
65.23		2	2	very sharp.	
74.50		1	—		
76.50		1	—		
77.30		1	1		
78.61		3	1.2	⊙ line double { 78.50 Fe .61 Ti	
79.85		2	?		
82.57		2.3	2	very sharp.	
——	4088.71				
90.73		1	1.2		
92.83		1.2	2		
95.65		1	1		
99.32		2	1		
99.94		1.2	1.2	sharp.	
4101.08		1	1		
05.31		1.2	1.2		
09.92		1.2	2.3	also Fe.	
11.91		2.3	2	sharp.	
12.86		2.3	1.2	very sharp.	
15.32		2	2	sharp.	
16.64		1.2	1.2		
21.79		1.2	—	sharp.	
——	4121.96				
22.31		2	1		
23.42		2	1.2	diffuse.	
23.68		2.3	1.2	diffuse.	
27.67		2.3	?	⊙ has 27.75=Fe. This line has perhaps a weak companion 27.69.	
28.20		2	?		
29.30		1.2	1.2		
31.38		1.2	?		
34.60		1.2	2	⊙ line double { 34.50 .60	

Titanium λ	R.	i		REMARKS	Thalén
		Ti	⊙		
4137.39		2.3	1	diffuse.	
43.16		1.2	?	diffuse; a group of fine ⊙ lines lies here; coincidence impossible to decide upon.	
51.11		2.3	1		
——	4157.94				
59.79		2.3	1		
61.67		1	2		
63.80		2.3	2		63.6
64.27		1.2	1		
64.80		1	1		
66.45		2	1		
69.46		2	1		
71.15		2.3	1	⊙ has { 71.00 Fe .15 Ti	71.6
72.04		2	2		
73.66		1.2	2	⊙ line close double 73.55. .66 Ti.	
74.20		1	1		
74.61		1.2	1		
83.45		1.2	1		
——	4185.05				
86.27		3.4	1.2		85.6
88.84		2	?		
4200.88		1.2	1	⊙ has a broad band of fine lines; decision impossible.	
03.58		2	1	⊙ line exceedingly weak.	
11.85		1.2	1		
——	4215.65				
24.96		2	?		
27.80		2	?		
38.00		2.3	1		37.1
45.66		1.2	—		
49.29		2	?		
51.77		2	1		
51.93		2	1		
——	4254.49				
56.18		2.3	1		
58.68		2	1	⊙ line triple { 58.68 .80 .95	
60.91		1	2		
61.75		2 +	?	between the ⊙ lines 61.65 and 61.90.	
63.28		3	1.2		63.6
65.42		1.2	2		
65.85		1.2	1		
66.37		1.2	1		
——	4267.94				
70.30		2	1.2		
72.57		2	?		
73.45		1.2	2		
74.73		3	1.2		73.6

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
4276.55		2	1	⊙ has a weak triple $\left\{\begin{array}{l}76.15\\ .35\\ .55\end{array}\right.$	
78.34		2	2.3		
78.95		1	—		
80.17		1.2	1.2		
81.49		2.3	1		
82.85		3	1.2	⊙ line close double; coincidence with the component toward V.	82.6
85.15		2.3	2		
86.15		3.4	2		
87.55		3.4	2		87.6
88.29		1.2	1.2		
89.23		3.4	2		
90.07		1.2	1.2		
90.37		2.3	2.3	"large" (Th.)	
91.07		3	3		91.3
91.32		2	2		
———	4293.24				
94.28		3	3.4	⊙ line perhaps double. K.-R. give a strong Fe line at 94.33.	94.4
95.91		3.4	1.2		95.6
98.82		3.4	1.2	Thalén observed these seven lines as a broad band.	
99.38		3	2		
99.79		3	1.2		
4300.19		3	2		99.8
00.73		3.4	2		
01.23		3.4	3		
02.08		2.3	2		
06.07		4	2.3		06.0
08.64		1.2	?		08.3
11.80		1.2	?		
13.01		3	2.3		13.3
14.50		2.3	1.2	⊙ line very close double $\left\{\begin{array}{l}14.40\\ \;\;.50\end{array}\right.$	14.3
14.95		3.4	2		
15.15		2	2	⊙ line close double $\left\{\begin{array}{l}15.15 \text{ Ti}\\ \;\;.28 \text{ Fe}\end{array}\right.$	
16.96		2	1.2		
———	4318.23				
18.83		3.4	3	Also a strong Ca line K.-R.: 18.83.	18.8
21.12		1.2	2		20.8
21.82		3	1.2	Thalén "large."	
25.30		3	1.2		24.3
26.50		3	1.2		
27.12		1.2	1		
30.85		1.2	2		
34.98		1.2	1	⊙ line the middle line of a weak triplet.	
38.05		3	2.3		38.3
38.62		1	1		
41.51		1.2	2		

Titanium λ	R.	i Ti	i ⊙	REMARKS	Thalén
——	4343.98				
4343.93		1	—		
44.47		1.2	2		
46.26		2	1		
46.76		1	2		
50.99		1	1		
53.01		1	—		
54.20		1.2	?		
55.44		1	1		
60.60		2	2		
61.31		1	—		
67.81		1.2	2	⊙ line strong double { 67.70 .80	
69.11		1.2	?		
69.82		2.3	?		
72.54		2	1		
74.97		1	1.2		
75.61		1	?		
——	4376.10				
79.40		2	3		
84.85		2	2	⊙ line close double { 84.85 .95	
87.00		1	1.2		
88.22		1.2	?		
88.69		1	?		
90.11		2	2		
94.04		3	1	⊙ line belongs to a weak triple.	93.8
94.19		1.2	—		
95.17		3.4	3		
95.99		1.2	2		
99.92		2.3	2.3		99.3
4400.74		1.2	1.2		
04.42		3	1.2		03.8
04.57		2	1		
05.07		2	?	In the shadow of 04.95 between this line and its companion 05.15. Line 04.95 = Fe scarcely visible on the plate.	
05.86		2	1		
07.85		1.2	2.3	⊙ line close double { 07.85 .95	
——	4407.85				
08.39		1.2	2		
08.70		1.2	2.3	⊙ line close double { 08.60 .70	
09.41		1	1.2		
09.71		1	1.2		
12.61		1.2	1	line 11.8 (Th.) missing.	
14.29		1	1		
16.70		2	1.2		
17.46		3	1.2	{	18.6
17.88		2.3	2.3		

Titanium λ	R.	i Ti	i ⊙	REMARKS	Thalén
4418.52		1.2	2		
21.92		2	1		
23.00		2.3	1		
24.58		1.2	—		
——	4425.60				
26.01		1.2	1	⊙ line narrow double { 25.90 26.00	
26.24		2.3	1.2		
27.28		4	2.3		27.6
30.19		1.2	1		
30.55		2.3	1		
31.46		2	—		
32.76		1.2	2		
33.75		1.2	1		
34.15		3	1.2		
34.54		1	1		
36.75		2	1		
38.38		1.2	?		
40.49		2.3	1		
41.45		2	1		
41.86		1.2	2		
43.16		1.2	1		
43.97		3	3		43.8
44.41		1.2	1.2		
44.72		1	2		
——	4447.90				
49.32		3	2	}	50.3
50.66		2	2		
51.07		3	2		
51.40		1.2	1	⊙ line wanting in R.	
53.48		3	2		53.3
53.87		2.3	1.2		
55.48		3	2		55.8
57.59		3.4	2	⊙ line double { 57.60 .70	58.3
59.62		1	—		
62.26		1.2	—		
63.52		2	1.2		
63.70		2	1		
64.60		1.2	2		
65.96		2.3	1.2		
68.65		3	2.3		69.3
——	4468.65				
69.32		1	1.2		
71.00		1.2	2		
71.40		2.3	1.2		
75.00		2.3	1		
79.86		2	1	⊙ line a weak companion to 79.80.	
80.72		2	1.2		
81.41		2.3	2		81.8
82.84		2	2		

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
4488.47		1.2	2		
89.24		2.3	1.2	⊙ line close double $\left\{\begin{array}{l}89.25\\ \ \ .35\end{array}\right.$	
92.70		1.2	1	⊙ line distinct. Wanting in R.	
——	4494.72				
95.19		3	1	⊙ line distinct. Wanting in R.	
96.33		3	2		96.9
97.90		1.2	1.2		
4501.43		3	2.3		01.6
03.92		2	1		
06.51		1.2	1		
08.21		1	—		
——	4508.45				
11.32		1.2	?	perhaps a ⊙ line.	
12.88		3	2		12.4
15.76		1.2	—		
18.18		3.4	2		18.4
18.84		2	1		
22.97		3	2		22.9
27.48		3	2.3		27.1
33.42		3.4	2.3	this group is in Th. a broad irresolvable band. “Très large.”	33.0
34.15		2.3	3		
34.97		3.4	2.3		
35.75		3	2.3		
36.12		3	2.3		
36.25		3	2.3		36.5
——	4536.25				
44.83		3.4	2.3		44.4
48.93		3.4	2		
49.79		3	2.3	⊙ line triple $\left\{\begin{array}{l}49.60\ \mathrm{Fe}\\ \ \ .79\ \mathrm{Ti}\\ \ \ .94\end{array}\right\}$ K.-K.: 49.64. (Fe)	49.8
52.62		3.4	2	⊙ line close double $\left\{\begin{array}{l}52.62\ \mathrm{Ti}\\ \ \ .72\ \mathrm{Fe}\end{array}\right\}$	52.7
55.64		3	2		56.2
58.02		1.2	—		
58.28		1.2	1.2		
60.08		2	1		
62.80		2	1		
63.60		1.2	1		
——	4563.94				
63.94		2.3	2.3		64.1
71.07		1.2	—		
72.15		3	2.3		72.4
75.71		1	—		
——	4578.72				
90.11		2	2		
94.28		1	1.2		
99.40		2	1		
4609.55		1.2	—		
——	4611.44				

Titanium λ	R.	i Ti	i ⊙	Remarks	Thalén
4614.47		1	—		
17.41		3.4	2		17.6
19.67		1.2	1.2		
23.24		3	2		23.9
29.47		2.3	2.3		29.9
34.87		1.2	1.2		
35.04		1.2	2		
35.71		1.2	1		
37.34		1	1		
——	4637.67				
38.04		1.2	1		
39.50		2.3	2		39.7
39.83		2.3	2		
40.11		2.3	2		
40.60		1	1		
45.36		2.3	1.2		44.9
50.16		2.3	1		
55.82		2	1		
56.20		2	1		
56.60		3.4	2		56.9
57.35		1.2	1.2		
67.76		4	2.3	⊙ line strong double { 67.60 Fe .75 Ti } K.-R.: 67.63	67.4
——	4668.30				
68.54		1.2	?	perhaps a very weak ⊙ line.	
75.27		2.3	1.2		
——	4679.02				
82.08		3.4	2		82.4
84.68		1.2	1		
87.08		1.2	—		
87.97		1.2	—		
88.56		1.2	1		
90.97		2	—		
91.50		3	3	⊙ line very close double; not separated. Ti corresponds to the component toward violet K.-R. give 91.59=Fe.	91.5
93.83		2.3	1		
97.10		2	?		
98.94		3	1.2		98.9
——	4703.98				
4710.34		3	1	⊙ line close double { 10.34 Ti .44 Fe	09.8
15.46		2	1		
22.77		2.3	1.2		
23.32		2.3	1.2		23.6
——	4727.62				
31.33		2.3	1		
33.58		2	1		
34.83		1.2	1		
42.28		2	?	possibly a weak ⊙ line.	
42.94		3	1.2		42.6

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
4747.84		2	1		
——	4754.22				
58.30		3	2		57.8
59.08		1.2	1		
59.44		3	2		59.3
66.48		2	?		
69.94		2	1		
78.44		2.3	1.2		
81.91		2	1		
——	4783.60				
92.65		2.3	2		92.4
96.36		2	1.2		
98.13		2	1		98.3
99.95		2.3	1.2	⊙ close double $\left\{\begin{array}{l}\text{4799.95 Ti}\\\text{4800.05 Fe}\end{array}\right.$	
——	4805.25				
4805.25		1.2	2.3	⊙ line double. Which component?	05.2
05.56		2.3	1.2		
08.70		2	1		
11.24		2	1		
12.40		1.2	—		
19.20		1.2	—		
20.56		3	1.2		20.4
——	4824.31				
25.63		1.2	1		
27.74		1.2	1		
36.25		2	1.2		35.9
41.00		3.4	2		40.9
44.13		1.2	—		
48.62		2	1		48.9
56.18		3	1.2		55.9
——	4859.93				
64.37		1.2	—	⊙ has 64.45; not coincident.	
68.44		3	1	⊙ double $\left\{\begin{array}{l}68.44\\ .55\end{array}\right.$	68.4
70.28		3	1.2		69.9
81.08		1.2	1	⊙ line uncertain. 73.9 (Th) wanting.	
82.53		1	—		
85.25		3.4	2		85.4
——	4890.94				
92.03		1.2	—		
93.25		1.2	—		
93.62		1	—		
4900.08		3	1.2		00.1
——	4903.48				
11.38		1.2	1.2		
13.76		3	1.2	⊙ has 13.75, 14.05.	14.0
15.40		1.2	—		
19.99		2.3	1		19.8
21.90		2.3	1.2		21.6

Titanium λ	R.	i		REMARKS	Thalén
		Ti	⊙		
4925.53		1.2	1		25.8
26.31		1.2	?		
28.50		2.3	1.2		28.3
—	4934.24		—		
37.94		1.2			38.0
38.51		2	—	quite near a ⊙ line, but displaced somewhat toward red.	
41.77		1.2	—		
48.40		1.2	1		47.8
64.90		2 —	?		65.3
68.75		2	1		68.5
73.25		2	2		73.0
75.52		2.3	1.2		76.0
77.92		1.2	1.2		
78.39		2	1.2		78.6
—	4978.78				
81.91		4	2.3		81.8
89.33		2.3	1.2		89.1
91.24		4	2.3	⊙ has 91.25 .45	91.1
97.26		2.3	1.2		
99.67		4	2.3		99.6
5001.16		2.3	1.2		02.0
—	5007.42				
07.42		4	3		07.6
09.81		2	1		
13.45		3	1.2		13.2
14.40		4	3		14.3
16.32		3.4	2		16.3
20.17		3.4	2		20.4
23.02		3.4	2		22.2
25.00		3	1.2		24.8
25.72		3	1.2		25.8
—	5036.10				
36.10		3.4	2.3		36.6
36.65		3.4	2		
38.55		3.4	2		39.2
40.12		3.4	2		40.2
40.78		2	1		
43.77		2	1		44.4
45.58		1.2	1		
53.06		2	1		53.3
54.30		1	—		
—	5060.25				
62.30		2	1		62.3
64.26		1.2	?		
64.82		3.4	2.3		65.4
66.12		2	1.2	⊙ line probably double.	66.5
68.47		1.2	1		
69.56		1.2	1		
71.66		2	1.2		71.2

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
5085.55		1.2	?	The line 77.5 in Th. missing.	
87.24		2.3	1		87.5
	5090.96				
5103.39		1	—		03.5
09.65		1.2	—		09.7
13.64		2.3	1+		14.1
20.60		2.3	1.2		21.0
——	5121.80				
29.32		1.2	2.3		29.7
33.12		1	—		
45.62		2.3	1.2		45.6
47.63		2.3	1.2		48.1
52.36		2.3	1.2		52.3
——	5155.94				
73.94		3	2		74.1
86.57		1.2	—		86.2
88.87		2	2.3	⊙ line double $\begin{cases} \text{88.87 Ti} \\ \text{89.05 Ca} \end{cases}$	89.4
93.15		3	2		93.4
94.25		1.2	1		
5201.32		1.2	1		01.6
——	5202.49				
06.30		1.2	3	⊙ line double; coincidence with the component toward red.	06.6
08.08		1.2	1		
10.55		3	2		10.6
12.50		1.2	1		
19.88		2	1	the line 18.6 (Th.) missing.	
22.87		2	1		
23.80		1.2	1	the line in Thalén is described as "large" and therefore probably includes the entire group.	
24 46		2.3	1.2		24.1
24.71		2	1		
25.15		2.3	2		
26.70		1.2	2		27.1
——	5230.01				
38.77		2	1		39.6
46.30		1	—		
46.75		1	—		
47.48		1.2	1		47.4
51.14		1	1		
52 26		2	1		52.1
56.01		2	—		56.1
60.18		1.2	?	perhaps a ⊙ line.	60.7
63.71		1.2	—		64.0
66.20		2.3	1.2		66.1
——	5266.73				
82.61		1.2	1.2	Thalén's lines 72.6, 68.3 missing.	
83.63		2.3	1		83.9
84.61		1.2	1.2		
89.02		1.2	-		88.9
95.95		2	1		96.6
97.42		2.3	1		97.8

Titanium λ	R.	i		REMARKS	Thalén
		Ti	⊙		
5298.61		2	?		99.6
5300.18		1	1		
——	5300.92				
36.96		1.2	2		38.1
38.54		1	1		
41.68		1	—		
51 28		2	1		51.7
66.85		1.2	—		
——	5367.67				
69.81		2.3	1.2		70.0
81.20		1.2	2		81.4
89.36		1.2	?		
90.23		2	1		
96.78		1.2	1		
——	5397.34				
97.28		2	2.3	Fe has 97.34 (K.–R.), Ti appears to be more refrangible.	97.3
5404.25		1.2	—		04.4
09.81		2.3	1		09.9
19.00		1.2	1.2		19.2
——	5424.27				
26 48		1.2	1		26.3
29.37		2.3	—		29.9
36.93		1.2	—	sharp.	
38.53		1.2	—		
46.80		2	2		47.1
——	5447.12				
49.40		1.2	—		49.3
53.88		1.2	1		
60.72		1.2	1		
——	5466.60				
71.43		2	1		71.8
72.90		1.2	1.2		
74.43		2	1		74.6
77.92		2.3	1		77.8
81.64		2.3	2		81.5
82.09		2.3	1		
——	5487.96				
*88.44		2.3	1		88.1
*90.88		3	1		90.2
5504.10		2.3	1		04.2
12.00		1.2	?		
12.72		3	1.2		13.2
——	5513.19				
*14.58		3	1.2		14.8
*14.78		3	1.2		
65.70		3	1		66.0
——	5569.84				

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*The asterisk signifies that the wave-lengths were derived from the preceding ⊙ line.

Titanium λ	R.	i		Remarks	Thalén
		Ti	⊙		
				All the following lines lie within a series of flutings which begin with a sharp edge at λ 5597.90 and extend with decreasing intensity toward the red. The flutings are all resolvable into elementary lines.	
5644.37		3	1.2		44.3
48.81		2.3	1		48.3
——	5658.09				
62.37		3	1		62.8
63.16		2	2		
75.61		3.4	2		75.7
80.15		2	1	⊙ line weak; not in R.	80.3
——	5688.43				
89.70		3	1		89.8
5702.92		2.3	1		02.7
08.46		2	?		
12.07		2	2.3	sharp.	
14.12		2+	?	perhaps a ⊙ line.	
15.30		2.3	2		15.2
16.71		2	?		
20.70		2	1	sharp.	
——	5731.98				
39.69		2.3	1		39.2
40.20		1.2	1	sharp.	
——	5754.89				
57.08		1.2	1.2		
62.52		2.3	1	diffuse; in Rowland, trace of a ⊙ line; not on the plate.	
66.56		2.3	1	diffuse.	
——	5772.36				
74.27		3	1		
81.04		1.2	1		
86.21		3	1	diffuse.	
——	5791.21				
5804.45		3	1	diffuse.	
——	5805.45				
23.95		1.2	—		
——	5831.84				
66.69		3.4	2		66.5
——	5884.05				
80.55		1.2	?		
——	5893.10				
99.56		3	1.2		5900.2

8. As for the accuracy of the wave-lengths here given, the probable error will seldom exceed ±0.02 tenth-meters. In order to guard against such systematic errors as are easily produced by a slight relative displacement of the metallic and solar spec-

tra on the photograph, only those plates out of the many available ones were measured which exhibited the greatest possible sharpness of definition, and on which the always present iron lines were in exact coincidence with the corresponding lines in the solar spectrum. That the resulting wave-lengths are in fact free from such errors is shown partly by the very satisfactory agreement in every respect with the measurements of iron lines by Kayser and Runge, and with those of a few titanium lines by Rowland, and partly by the agreement of the two series of measurements of titanium lines executed on different plates. Comparisons with the iron spectrum of Kayser and Runge have already been given. If the above table is compared in like manner with Rowland's catalogue of normal wave-lengths, we obtain from the titanium lines in the latter the following short table:

Rowland	H.	Rowland	H.
3510.99	10.98	4691.58 Ti Fe	91.50
3564.68	.....		.....
3635.62	35.61	4805.25	05.25
3653.64	53.61	4900.10	00.08
3722.69	22.70	4973.27	73.25
3743.50	.....	4981.91	81.92
3924.67	24.67	4999.69	99.67
4306.07	06.07	5007.43	07.42
4391.15 Fe Ti	.....	5014.42	14.40
	.....	5020.21	20.17
4501.44	01.43	5036.11	36.10
4508.46 Ti ?	.....	5064.83	64.82
4563.94	63.94	5154.24 Ti ?	.....
4578.73 Co, Ti	.....	5188.86	88.87
4590.13	90.11	5193.14	93.15
4629.51	29.47	5210.56	10.55
		5675.65	75.61

It will probably be admitted that this agreement leaves nothing further to be desired. That lines which Rowland regarded as titanium lines are not found in my table, is no doubt due to the fact that by me they have been regarded as iron lines and have therefore been excluded.

A judgment of the close agreement of the two series of measurements of titanium with one another, by which is proved the absence of systematic errors in consequence of a displacement of the spectrum either in taking the photograph or by the distortion of the gelatine film, is most easily obtained by the aid of the following table, which gives the number of cases in which the difference of wave-lengths of the two series reaches the value set opposite:

$\Delta =$ Tenth-meters	$N =$
0.00	125
.01	203
.02	139
.03	91
.04	45
.05	30
.06	19
.07	11
.08	6
.09	3
.10	3

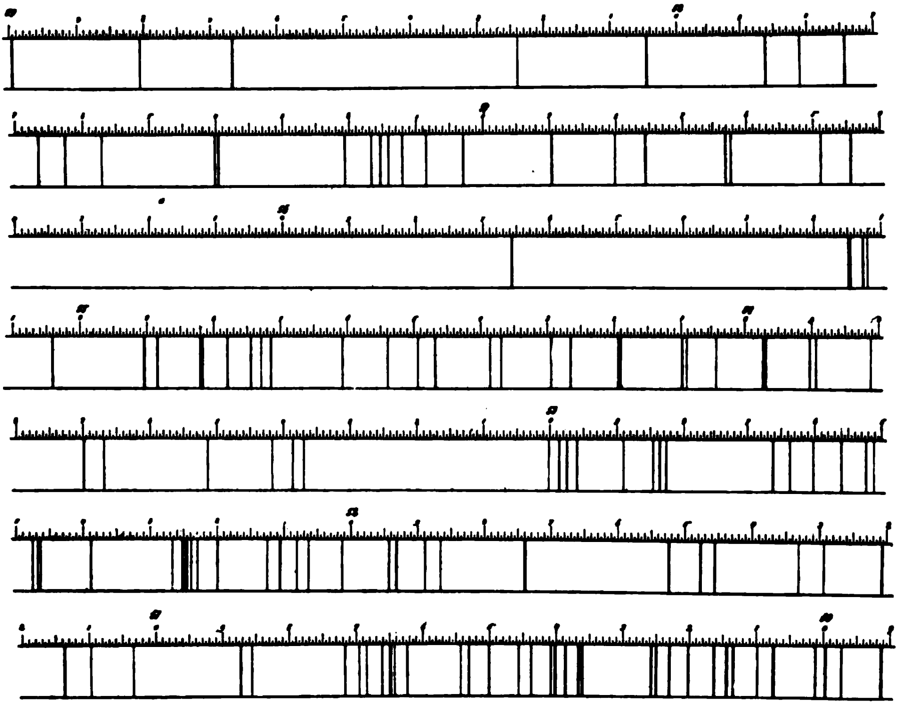
The number of cases in which the difference of wave-lengths measured on different plates exceeds 0.05 tenth-meters, or the approximate limits of the probable error, is accordingly only 42 out of the 675 lines compared, or about 6 per cent., a result which may be regarded as perfectly satisfactory.

9. The comparison of Thalén's wave-lengths with those herein given is of especial interest. If we form the differences H.-Th. for the 160 lines common to both spectra, we find that they are not only small but in general of quite a fortuitous character. We may therefore conclude that the probable error of one of the wave-lengths given by Thalén is only ± 0.24 tenth-meters, a degree of accuracy which at that time was quite unparalleled.

10. The presence of titanium in the solar atmosphere is confirmed, with even superfluous evidence, by these investigations. If we separate the coincidences and non-coincidences with the aid of columns 3 and 4, and arrange them according to the intensity of the titanium lines, the following table is obtained:

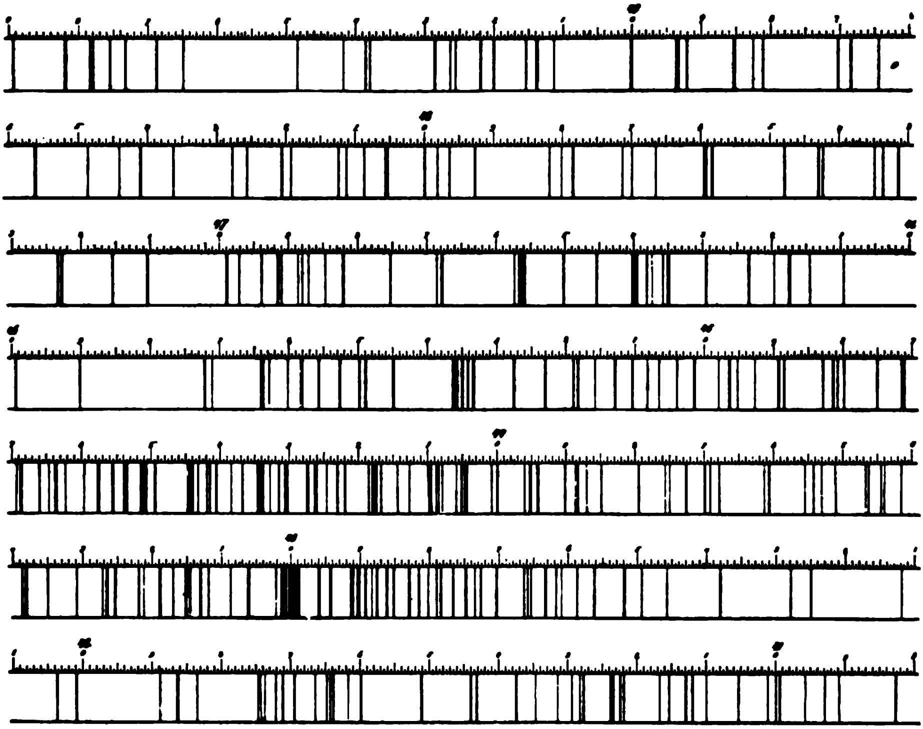
i	Coincident	Non-coincident
1—1.2	193	106
2—2.3	231	50
3—3.4	124	0
4—4.5	12	0
5—6.	2	0

PLATE IV.



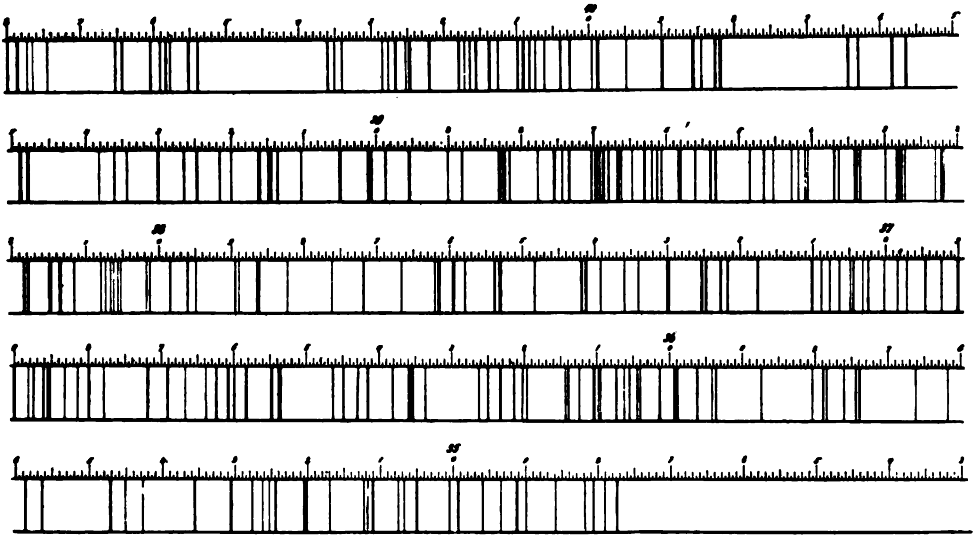
THE ARC SPECTRUM OF TITANIUM

PLATE V.



THE ARC SPECTRUM OF TITANIUM

PLATE VI.



THE ARC SPECTRUM OF TITANIUM

The coincident lines therefore form a little more than 78 per cent. of all the lines observed. If we exclude the weakest class altogether, in consideration of the probability that quite a number of the lines in it do not belong to titanium, the percentage of coincidences rises to 88. As in the case of chromium, a consideration of the intensities of the metallic and solar lines shows a general agreement, which is, however, often far from perfect.

MINOR CONTRIBUTIONS AND NOTES.

HARVARD COLLEGE OBSERVATORY. CIRCULAR NO. 10.

SIX NEW VARIABLE STARS.

LISTS of suspected variable stars are published in the *Results of the National Argentine Observatory*, Vol. XVI, p. 32, and Vol. XVII, p. 11. These lists contain 527 and 232 stars respectively, in which the magnitudes were found to be discordant in the observations of the Cordoba *Durchmusterung*. Especial attention is there called to 26 stars, which are indicated by exclamation marks. These stars have been looked for on a number of Draper Memorial photographs by Miss E. F. Leland and the results confirmed by Mrs. Fleming. From this examination confirmation of the variability of the stars —24° 12600, —27° 15203, —33° 185, —34° 224, —38° 138, and —38° 13089 has been obtained, the change exceeding one magnitude in all cases. The variation of —22° 13401, —22° 13700, —23° 8083, —24° 13621, —25° 1197, —30° 12799, —33° 13321, —35° 11936, —35° 14568, —37° 11462, —38° 2639, and —41° 12260 on from 8 to 25 nights did not exceed two or three tenths of a magnitude, and the variation of these stars is accordingly not as yet confirmed. In each of these cases two comparison stars were selected, differing about half a magnitude in brightness, one a little brighter and the other a little fainter than the suspected variable. The star —22° 15937 does not appear on photographs taken on 16 nights, although the adjacent star, —22° 15939, is well shown on all. The confirmation by Miss Leland of the variation of —24° 7693 has already been announced (*H. C. O. Circular No. 7*). The confirmation by Mr. Robert H. West of the variation of —25° 1602, —26° 892, and —30° 375, has already been announced by him (*Ast. Jour.* 16, 85). —25° 1602 and —30° 375 have also been confirmed here from the examination of the photographs. —30° 19092 is R Piscis Austrini. The variation of —33° 13234 was discovered independently by Mrs. Fleming (*H. C. O. Circular No. 6*). The star in the Bonn *Durchmusterung*, —22° 4346, and not found by Thome, does not appear on photographs taken on 8 nights.

It therefore appears that of these 26 stars, 12 are variable, the variability of 12 is not confirmed, and 2 do not appear on the photographs examined.

The laborious work of taking out all the photographs of the regions containing these six new variable stars, measuring the brightness, the magnitude at maximum and minimum, the period and form of light curve, as has been done for other variable stars discovered here, is now in progress.

EDWARD C. PICKERING.

AUGUST 13, 1896.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 11.

A NEW SPECTROSCOPIC BINARY μ^1 SCORPII.

FROM an examination of the Draper Memorial photographs Professor Solon I. Bailey has found that the star μ^1 Scorpii is a spectroscopic binary. This star is $-37°11033$ = *S. M. P.* 5794. Its approximate position for 1900 is in R. A. $16^h\ 45^m.1$, Dec. $-37°\ 53'$, and its photometric magnitude is 3.26. Its spectrum is of the first type and contains the additional lines characteristic of the Orion stars. It, therefore, belongs to Class B according to the notation of the Draper Catalogue. The star μ^2 Scorpii follows about 28^s and is $1'.7$ north, and its photometric magnitude is 3.74. The spectra of both stars, therefore, appear side by side in the photographic plates. In some they are scarcely distinguishable, while in others the lines of the first star are broad and hazy, some of the faint lines appearing distinctly double. The lines in the spectrum of the second star are always single and well defined. One of the components of the binary is fainter than the other, so that the lines of its spectrum are sometimes of greater, and sometimes of shorter, wave-length than those of the brighter component. The difference in intensity also seems to change as if due to a variation in the light of one of the components.

An examination of the plates already sent to Cambridge shows that the spectrum of this star was photographed on October 2, 1892, July 20, 1894, and July 31, 1894. On the first of these plates the lines are single, on the second they are wide and hazy, and on the third they are double. When Mrs. Fleming examined these plates in October 1894, she recorded on the second of them "Lines double?" and on the third of them "Lines double." They were laid aside for further examination but were overlooked.

The changes are so rapid that they are perceptible in successive plates having exposures of one hour. From a discussion of fifty-two photographs Professor Bailey has derived a period of thirty-five hours and a nearly circular orbit.

An independent discussion made here shows that all the observations, including those of the early photographs, may be represented by the formula, *J. D.* 2412374.52 + 1.4462 *E.* which gives an average period of $34^h\ 42^m.5$ with an uncertainty of less than a tenth of a minute. Ten observed times when the lines were single are represented with an average deviation of thirty-eight minutes each. The maximum deviation is less than an hour. Further observations will, however, be required to make sure that no other assumption is possible for the total number of epochs since 1892. In nineteen photographs the lines of the fainter component were found to have greater, and in fourteen, shorter, wave-lengths than those of the brighter component. This was confirmed later, in each case, by the formula.

Only two stars of this class are already known. The first, ζ Ursae Majoris, was found by the writer in 1889. The period appears to be about fifty-two days, but it is irregular, perhaps owing to the presence of a third body and the time during which the lines are widely separated is short. The second star, β Aurigae, was found later in the same year by Miss A. C. Maury. The changes appear to be perfectly regular with a period of a little less than four days.

EDWARD C. PICKERING.

August 31, 1896.

A NEW ASTROPHYSICAL OBSERVATORY.

WE take pleasure in announcing the establishment of a new observatory at Rössgen, Mittweide, Saxony. The principal instrument, which will be ready for use by the middle of October, is a refractor of 170^{mm} aperture, made in the workshop of Hans Heele in Berlin. It is provided with both visual and photographic objectives, and the mounting embodies a number of new features. The programme of work prepared by Dr. Friedrich Krueger, the director of the observatory, includes:

(1) The formation of a photometric catalogue of all colored stars within the limits of the director's catalogue of colored stars.

(2) Photometric determinations of comparison stars used in the

observation of variables, including such stars as are communicated to the director by observers of variables and those which are found in published papers.

(3) Construction of star charts, by the aid of photography, of regions containing variables.

HUBERT A. NEWTON.

The recent death of Professor Hubert A. Newton, of Yale University, removes one who has contributed largely to cometary and meteoric astronomy. Born in Sherburne, N. Y., March 19, 1830, of a mother locally famed for her mathematical skill, Newton gave early promise of his power as a mathematician. After preparing for Yale in the school of his native town, he entered college at the age of sixteen. His course was followed with success; among other distinctions he won the first prize in mathematics and gained some reputation as a public speaker. His study of mathematics was continued after graduation, and in 1853 he was appointed tutor at Yale University. The work of only two years brought him, at the age of twenty-five, an appointment to a full professorship in the mathematical department, where he served with distinction up to the time of his death.

After some years devoted to investigations of a purely mathematical character Professor Newton undertook, shortly after the meteoric shower of 1853, the researches for which he is best known. He was able to identify the meteors with the comet of 1866, and to predict their periodical return. The long series of papers published during the remainder of his life greatly stimulated the scientific study of meteors and their relations with comets. As Secretary to the Board of Managers of the Yale Observatory, and for two years as Director, he was identified from its inception with this well-known institution. Although his theoretical researches left him little time for observational work, he did much to encourage the important investigations of Dr. Elkin and his associates. For all of these services to science he received deserved recognition from learned societies at home and abroad. His personal character endeared him to a large circle of friends, who will unite with the many who knew him only by reputation in mourning his loss.

REVIEWS.

On the Equipment of the Astrophysical Observatory of the Future, with two appendices: Appendix I., *On the Support of Large Specula*. Appendix II., *On Making the Siderostat an Instrument of Precision*. By G. JOHNSTONE STONEY, M.A., D.Sc , F.R.S. *Monthly Notices of the Royal Astronomical Society*, Vol. LVI., pp. 452–459, June, 1896.

THE general design and equipment of an observatory which is to be devoted simply to the science of observational astronomy has now become well established, and indeed, from the nature of the work undertaken, admits of but little variation. But astrophysical work has now come to occupy such an important place in astronomical science as to demand observatories specially designed and equipped for its prosecution. The number of such observatories is as yet small and the general lines upon which different ones have been fitted up vary widely. Some, like the astrophysical observatory at Potsdam, have retained the equatorial, simply attaching all the necessary apparatus to the eye-end of the telescope. Others, of which the one established by Langley at Allegheny was one of the first, have adopted some form of the siderostat, usually the Foucault, in connection with fixed observing apparatus.

This being the case, Dr. Stoney's discussion of the form and equipment of astrophysical observatories is especially seasonable, although one might wish that it were more extended. The use of the equatorial, for example, is not considered at all, the author taking the ground that some form of siderostat is always to be preferred for astrophysical work. With this conclusion many astrophysicists will disagree. Dr. Stoney's objections to the equatorial are: (1) The expense of the mounting and of the movable dome. (2) The fact that the observing apparatus must be attached directly to the eye-end of the telescope and move with it, and that this necessarily precludes the use of certain instruments, of which the radio-micrometer and the recently invented apparatus of Captain Abney for producing monochromatic images, are quoted as examples. As regards the first objection, it is to be questioned whether the cost of an equatorial mounting itself will greatly exceed the cost of an efficient siderostat of the same clear aperture, for we must remember that the use of the latter involves the use of at least one optical flat from one and one-half to two times the size of the telescope objective. The cost of the dome is undoubtedly greater than the cost of the buildings necessary to contain a siderostat, especially when the telescope has a very small angular aperture and consequently great focal length. Many plans, however, have been proposed for doing away with the expensive dome construction, and it is quite possible that some arrangement quite as efficient, and, for large telescopes, far less expensive, may before long be arrived at. One arrangement which has recently suggested itself to the reviewer would be to use a short cylinder of a diameter somewhat greater than the focal length of the telescope, and of a length somewhat greater than the length of the declination axis, mounted with its own axis horizontal and passing through the point of intersection of the polar and declination axes of the telescope. This cylinder would be mounted on its lower side on a horizontal ring which surrounds the base of the telescope mounting and upon which it may revolve about a vertical diameter. The lower half of the inner cylindrical surface could be cut into steps to form a series of observing platforms for different altitudes, one-half of the upper surface being cut away to form the usual slit extending from the horizon to the zenith. In order to increase the stability in high winds it might be advisable to place a bearing at the top of the cylinder, the box of which would be secured in position by means of steel guy ropes.

The second objection to the equatorial is, so far as the actual use of astrophysical instruments is concerned, more apparent than real. There are many forms of present laboratory apparatus which could not, it is true, be attached to the eye-end of a telescope, but there is not so far as the reviewer is aware any important astrophysical work that could not be carried on with properly chosen types of instruments equatorially mounted. For example, while the radio-micrometer cannot be used in this way, the bolometer can be with great facility, and the latter instrument has some other important advantages over the former, especially in spectrum work. Similarly the Hale spectroheliographs are likely to give better results in securing monochromatic images of the Sun than the Abney form of instrument, and no difficulty is found in adapting them to use with the equatorial; in fact, it is extremely doubtful whether they could be used with equal advantage in any other way. The equatorial has in general the great advantage of simplicity, of minimum loss of light, and of maintaining the position of the observing instrument with respect to the image constant. In accuracy of following also the simple equatorial is superior to any form of siderostat except those in which the specula are directly attached to and move with the telescope, as in the polar heliostat or the Coudé equatorial. The last three advantages are of primary importance in all photographic work in which prolonged exposures are necessary, and also in stellar spectroscopic work either visual or photographic. Dr. Stoney says, "The only defect which the siderostat has, namely, that the image furnished by it slowly rotates in the field of view, is of no detriment for stellar spectroscopy." Only those who have had actual experience in the work know how important it is to keep the slit of a stellar spectroscope parallel to the direction of the motion in right ascension. The great advance in stellar spectroscopic work will, in the opinion of the reviewer, come in the use of larger apertures of telescope and the substitution of reflectors for refractors, a substitution the many advantages of which have been already frequently enumerated by the writer.[1] In the case of very large apertures, too, the use of one or two additional specula of the same aperture as that of the telescope (as would be necessary in any form of siderostat), would very seriously increase the expense and the difficulty of mounting and guiding, additional arguments for adhering to the simple equatorial form.

One great disadvantage of this form of mounting which was not stated by Dr. Stoney and which really seems to demand more than anything else the use of a siderostat for some special classes of work, is the inability to keep the large dome, in which the equatorial is generally mounted, at a constant temperature and under constant hygrometric conditions.[2] When the observing instrument is small this difficulty may be overcome by enclosing it in a non-conducting case, or better in a series of concentric copper cylinders or boxes, but only at some sacrifice of convenience of manipulation. Besides the comfort of the observer is sometimes an important factor in determining the success of the work, and this can without doubt be best secured by using some form of siderostat. Of these the reviewer agrees with Dr. Stoney in considering the polar siderostat, in general the most advantageous. In this connection it may be well to point out the great advantage which would result from reflecting the beam down the polar axis instead of up as is usually done; this advantage being that for those parts of the sky to which the instrument is most frequently directed, *i. e.*, the regions in the neighborhood of the celestial equator, the speculum is nearly vertical and therefore in a position of minimum flexure, instead of nearly horizontal, as in the usual arrangement.

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[1] See particularly *Phil. Mag.*, July 1894, and Oct. 1894. *A. and A.*, Dec. 1894. *Ap. J.*, 1, 70; Jan. 1895, 1, 232; March 1895, 3, 182; and March 1896.

[2] Of special importance for work with the spectro-bolometer in which a rock-salt prism is employed.

Another important advantage is that in this arrangement the mirror of a polar heliostat may be mounted directly on the lower end of the polar axis of an ordinary equatorial and the one mounting, and what is perhaps even more important the one dome, thus made to serve perfectly for two independent instruments. As the tube of the polar heliostat lies in the prolongation of the polar axis of the equatorial it can never interfere with the telescope of the latter in any position of use. It is frequently very desirable to carry on two independent lines of work on the same object, particularly the Sun, simultaneously, and in such a case this arrangement offers great advantages. By clamping the mirror mounting to the telescope axis in different positions with respect to the declination axis, the two instruments may be used on different objects, but in the latter case two independent slit openings in the dome would be necessary.

The coelostat has, as Dr. Stoney points out, some very important advantages, and it deserves to be more generally used than it has been heretofore. The latter instrument ought to prove especially serviceable for spectroscopic and radiometric studies of solar details—particularly on eclipse expeditions—on account of its simplicity and the ease with which it can be set up and controlled. The author's plan of combining the polar heliostat and the coelostat is in some respects a good one, but it is open to the objection that the two instruments cannot be used together even if the mirrors are on opposite ends of the polar axis, owing to the different rate of rotation necessary. For this reason the combination of the polar heliostat and the equatorial as suggested above would seem more economical and efficient.

The merits and advantages of the s'Gravesande, or, as it is commonly known, the Foucault type of siderostat are, in the opinion of the reviewer, generally overrated. The beauty of the geometrical solution and the fascination of the idea of being able to maintain the telescope and all its connected observing apparatus fixed and immovable in a horizontal plane, in a room furnished with all the conveniences of a laboratory, is apt to blind one to the inherent difficulties of the mechanical design ; one of the greatest of these being the extremely unfavorable angle at which the driving mechanism acts when the object in the field is more than 50° from the zenith.

It is pretty safe to say that these difficulties will always prevent the use of this instrument for work requiring extreme precision and steadiness of image. The performance of this instrument can no doubt be greatly improved by careful attention to mechanical details, particularly those having to do with the driving connection between the equatorial axis and the mirror support. The rectilinear motion described by Dr. Stoney in Appendix II. will, if carefully made, no doubt work better than the sliding joint usually employed in making this connection, but in the form shown it is cumbrous and lacks the rigidity that is desirable at this point. A modified form of the Hart or Peaucellier straight line motion, or a well made ball-bearing attached to the end of the declination axis and arranged to allow of both longitudinal and circumferential motion on the driving rod attached to the back of the mirror, would probably work better in actual practice.

The form of mirror support described in Appendix I. is most ingenious and ought, so far as preventing flexure of the mirror is concerned, to act admirably. A mounting designed on exactly the same principle as that made use of in Dr. Stoney's arrangement, was devised several years ago by Mr. Ritchey, the optician of the Yerkes Observatory, but no description of it was published. More recently the same plan independently suggested itself to the writer of this review. In the latter case, as well as in the form finally adopted by Mr. Ritchey, it was proposed to make the inner ends of the levers bear directly against the glass, the outer ends being weighted so as to just support the weight of that portion of the glass resting on the inner end. Three fixed points on the back and three fixed points on the edge kept the mirror in an invariable position with respect to its mounting. The use of the air cushion has some advantages, but it has the objectionable feature of bringing the back of the mirror into contact with a considerable surface of metal. In order to perform best under varying temperature conditions both the back and edge of the mirror should be as fully exposed as possible,[1] and this condition is best secured by supporting the mirror on a number of rounded, non-conducting pins of wood or hard rubber, raised some distance above the ends of the levers or part of the mounting in which they are inserted.

But it must be remembered that the question of the performance of large mirrors in different positions is not by any means a question of the mounting alone. Much of the trouble experienced with specula of even moderate size is undoubtedly due to a want of homogeneity in the glass and insufficient thickness of the latter. The excellent performance of the Coudé Equatorials, in which two optical flats are employed, one of which assumes nearly every possible position, is attributed by M. Loewy to the relatively great thickness of the mirrors in comparison to their diameter. He considers that this ratio should not be less than one-fifth or one-sixth even for the very largest specula, a much larger ratio than has been usually employed. If discs of this thickness were employed and care were taken to have the glass as homogeneous and as thoroughly annealed as that used for refractors (freedom from striæ and bubbles is not so important), great improvement in the performance of reflectors would undoubtedly result; we might indeed then hope to rival the performance of the giant refractors which have recently been constructed.

F. L. O. WADSWORTH.

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[1] **Large mirrors ought to be polished on the back and edge as carefully as on the front surface. They should then be silvered *all over*. Neglect of these precautions will invariably cause the mirrors to warp more or less when the temperature of the surrounding air changes.**

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

EDITORS. On Photographing the solar corona. Obs'y 19, 296–298, 1896.

EDITORS. The approaching solar eclipse. Obs'y 19, 293–296, 1896.

LOCKYER, J. N. The Total Eclipse of the Sun, April 16, 1893. (Abstract.) A. N. 140, 359–360, 1896; Obs'y 19, 272–274, 1896.

PERRINE, C. D. Some recent Sun-spots. Pub. A. S. P. 8, 225–226, 1896.

STONE, E. J. Solar Eclipse without Instrumental means. M. N. 56, 451–452, 1896.

VALLOT, J. Expériences actinométrique faites au mont Blanc, pour déterminer la constante solaire. C. R. 122, 1530–1532, 1896.

3. STARS AND STELLAR PHOTOMETRY.

ANDERSON, T. D. New Variable Star in Hercules. A. N. 141, 104, 1896.

DOBERCK, W. A formula to correct double-star observations for refraction. Obs'y 19, 268–270, 1896.

EVERETT, ALICE. Galactic Longitude and Latitude of poles of Binary-star Orbits. M. N. 56, 462–466, 1896.

GILL, D. Sur cinq photographies de la région entourant η d' Argus. C. R. 123, 29, 1896.

HISGEN, J. Maxima und Minima veränderlicher Sterne. A. N. 141, 94–98, 1896.

HUSSEY, W. J. Nova Z, Centauri and the Nebula surrounding it. Pub. A. S. P. 8, 220–222, 1896.

HUSSEY, W. J. The Companion of *Sirius* and its brightness according to photometric theory. Pub. A. S. P. 8, 183–186, 1896.

Pickering, E. C. Miscellaneous Notes. A. N. 141, 37, 1896.

Pickering, E. C. Ten new variable Stars. A. N. 141, 34–37, 1896.

Roberts, A. W. Note on the period of T Centauri. M. N. 56, 500, 1896.

4. STELLAR SPECTRA, DISPLACEMENTS OF LINES AND MOTIONS IN THE LINE OF SIGHT.

Pickering, E. C. Stars having peculiar spectra. A. N. 141, 169, 1896.

5. PLANETS, SATELLITES AND THEIR SPECTRA.

Abetti, Osservazioni dei satelliti di Giove. A. N. 141, 134–135, 1896.

Barnard, E. E. Note on Saturn. A. N. 141, 79, 1896.

Barnard, E. E. Note on the Table of Measures of Saturn's Ring. Obs'y 19, 276, 1896.

Brenner, L. Ueber die Flecke auf dem Aequatorealgürtel des Saturn. A. N. 140, 353–355, 1896.

Campbell, W. W. Review of Lowell's *Mars*. Pub. A. S. P. 8, 207–220, 1896.

Crommelin, A. C. D. Note on a possible eclipse of Jupiter's second Satellite by the shadow of the third, March 30, 1896. M. N. 56, 474–475, 1896.

Denning, W. F. The belts and spots on Saturn. A. N. 141, 171, 1896.

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Gledhill, J. On certain phenomena presented by Jupiter's Satellites and their shadows during transit, with a note on the red spot; and on some methods of observing the transits of bright and dark spots across the central meridian. M. N. 56, 494–500, 1896.

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Mysz, K. Jupiter-Beobachtungen . . . . zu Pola. A. N. 140, 369–374, 1896.

Ravené, G. Ueber die Masse der Asteroiden. A. N. 140, 355–358, 1896.

Weinek, L. Sur les photographies lunaires offertes à l'Académie. C R. 123, 349–350, 1896.

6. COMETS, METEORS AND THEIR SPECTRA.

Denning, W. F. The August Meteors. Obs'y 19, 300–301, 1896.

COLTON, A. L. Photographs of Comet Perrine, 1896 *a*. Pub. A. S. P. **8**, 194, 1896.

DOBERCK, W. Radiants of Shooting-Stars Observed at Hongkong (continued). A. N. **140**, 375–378, 1896.

GREDILLA Y GAUNA. Étude pétrographique de la pierre météorique tombée à Madrid le 10 février 1896. C. R. **122**, 1559–1560, 1896.

LYNN, W. T. Early Observations of the Zodiacal Light. Obs'y **19**, 274–275, 1896.

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NYLAND, A. A. Die Lyriden von 1896. A. N. **141**, 101, 1896.

SCHWARZSCHILD, K. Ueber die Stabilität der Bewegung eines durch Jupiter gefangenen Cometen. A. N. **141**, 1–7, 1896.

STONEY, G. J. On the Importance of Accurately Observing the Leonids this year. M. N. **56**, 459–462, 1896.

7. NEBULÆ AND THEIR SPECTRA.

STRATONOFF, W. Nouvelles nébuleuses dans les Pléiades. A. N. **141**, 103, 1896.

9. EXPERIMENTAL AND THEORETICAL PHYSICS.

MALTÉZOS, C. Sur les rayons limites ($\lambda = 0$). C. R. **122**, 1533–1534, 1896.

RAMSAY, W. and COLLIE, J. N. Sur l'homogénéité de l'argon et de l'helium. C. R. **123**, 214–216, 1896.

ROOD, O. On the Regular or Specular Reflection of the Röntgen Rays from Polished Metallic Surfaces. Am. Jour. (4) **2**, 173–180, 1896.

SMOLUCHOWSKI DE SMOLAN. Recherches sur la dépendance entre le rayonnement d'un corps et la nature du milieu environnant. C. R. **123**, 230–233, 1896.

10. THE SPECTRA OF THE ELEMENTS.

DE GRAMONT, A. Sur le spectre du phosphore dans les sels fondus et dans certains produits métallurgiques. C. R. **122**, 1534–1536, 1896.

11. PHOTOGRAPHY.

COLSON, R. Action du zinc sur la plaque photographique. C. R. **123**, 49–51, 1896.

12. INSTRUMENTS AND APPARATUS.

STONEY, G. J. On the Equipment of the Astrophysical Observatory of the Future; On the Support of Large Specula; On Making the Siderostat an Instrument of Precision. M. N. **56**, 452–459, 1896.

13. **GENERAL ARTICLES.**

EDITORS. The Astrographic Chart Conference. Obs'y 19, 262–264 1896.

SCHUMANN, R. Ueber den Einfluss einer unsymmetrischen, veränderlichen Refraction auf die Polhöhenschwankung. A. N. 141, 81–83, 1896.

WILSING, J. Ueber die Genauigkeit photographischen Messungen und über eine Bestimmung des Thermometercoefficienten des Potsdamer photographischen Refractors. A. N. 141, 89–93, 1896.

NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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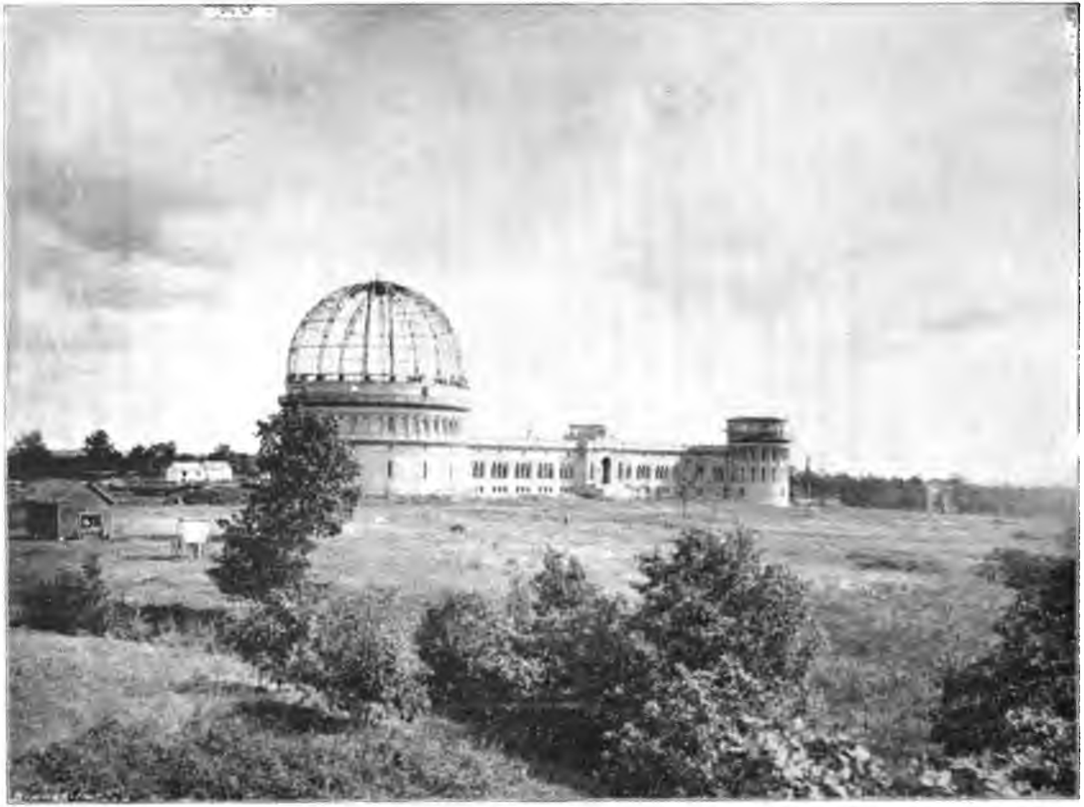
PLATE VII.



YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

AS IT APPEARED IN SEPTEMBER 1896.

THE

ASTROPHYSICAL JOURNAL

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A FURTHER STUDY OF THE EFFECT OF PRESSURE ON THE WAVE-LENGTHS OF LINES IN THE ARC SPECTRA OF CERTAIN ELEMENTS.

By W. J. HUMPHREYS.

IT has been shown[1] by Mohler and myself that, with the possible exception of the lines of the carbon bands, the wave-lengths of the lines in the arc-spectra of the twenty-three elements we examined increase with increase of pressure about the arc, that this increase is very different for different elements, and that it is always proportional, for any given element, to the wave-length and to the increase in pressure. It was also shown that the increase in wave-length, shift as we called it, is approximately proportional to the product of the coefficient of linear expansion of the substance in the solid state and the cube root of the atomic volume, that it is inversely proportional to the absolute melting points of the elements in question, and finally, that in most cases the cube roots of the atomic weights of the elements of a Mendelejeff group are proportional to the shifts of their lines.

In view of these facts it seemed desirable to examine the effect of pressure on the wave-lengths of the lines of other elements. This was done, and the results are given in the following tables. The method of obtaining the photographs of the spectra, and of measuring them, was the same in this as in the former investigation. As before, the pressure about the arc was obtained by pumping air into a closed cylindrical vessel provided with a quartz window and suitably constructed stuffing boxes for the carbons. (This apparatus was devised and constructed several years ago by Professor Rowland for the purpose of sometime investigating the effect of pressure on arc-spectra.) About one hundred and seventy-five negatives were obtained, and the best of them carefully measured. The results of the measurements are given in Table I., in which the upper numbers in the line of each wave-length are the observed shifts in thousandths of an Ångström unit and the lower their values for wave-length 4000. As far as possible the wave-lengths are taken from Professor Rowland's table of solar wave-lengths, in process of publication in the ASTROPHYSICAL JOURNAL, and from a former table of his published in *Astronomy and Astrophysics*;[1] a few are taken from other sources, but it was necessary to determine many of them by comparison with known lines in their neighborhood. As exact wave-lengths are not aimed at, only such approximation is given as will serve to surely identify the line in question.

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[1] *Ap. J.*, February 1896.

It will be noticed that just as the calcium lines H and K, as shown in the former paper, each shift half as much as the calcium line near G, so too, approximately, the same thing holds for the three analogous lines of strontium and of barium. This made it necessary to divide the strontium and the barium lines each into two groups, marked A and B, as was done in the case of calcium.

It has been suggested by Schuster[2] that the shift is probably due to the "proximity of molecules vibrating in equal periods." The suggestions of so eminent an authority should always receive most careful attention, but that the shifts of the spectral lines under the given conditions, are due to the cause mentioned seems impossible, since they are practically independent of the amount of material in the arc; a fact well established before the publication of Schuster's suggestion, and established, too, by the very process he proposed, that is, by varying between wide limits the quantity of material in the arc. The substance that showed this quite as well if not better than any other was titanium. The carbons used contained traces of a dozen or more impurities, of which titanium was one. This gave a few very fine but quite measurable lines whose width was practically the same under different pressures. Photographs of titanium spectra were taken with increasing amounts of material in the arc till the quantity was made as great as possible, but the shifts of the lines remained practically the same for the same pressures. The effect of quantity of material on the shifts of most lines at least, if it have any value at all, is certainly of the second order in comparison with that of pressure.

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[1] *A. and A.*, 12, 1893.

[2] *Ap. J.*, April 1896.

Since the coefficient of linear expansion is known for only about half a dozen of the elements given in Table I., it is impossible to make many tests of the relation between shift and the product of linear expansion by the cube root of the atomic volume. In one case, that of antimony, by taking the expansion along the axis of the crystal, the agreement is fairly close, but the results for arsenic, mercury, potassium, and rubidium are very far wrong. It should be stated, however, that the coefficients of expansion have been taken at 40° C., and that as mercury is a liquid at this temperature while the other elements examined are solids, an exact comparison between them cannot be made. Besides, as the coefficients of expansion depend upon temperature, no exact comparison can be made between the properties of the metals and their coefficients of expansion if these are taken at the same temperature. Possibly the coefficients of expansion should be taken at a fixed distance from the melting points. At any rate the greatest want of agreement is given by those metals which, like mercury, potassium, and rubidium, have the lowest melting points.

The reciprocals of the absolute melting points continue to be, in most cases, quite approximately proportional to the shifts of the lines of the respective elements. This is shown in Table II., in which S is the shift in thousandths of an Ångström unit for wave-length 4000 and a pressure of twelve atmospheres. T is approximately the absolute melting point, as given in Nernst's *Theoretical Chemistry*. $\frac{48600}{T}$ gives the quotient indicated. This number is the same that was used in the article by Mohler and myself, already referred to, and was taken to make the observed and calculated shifts of the iron lines agree.

The large number of elements that have been examined, forty-six in all, makes necessary a modification of the statement concerning the connection between their atomic weights and the shifts of their lines. The connection is this: The shifts of the spectral lines of the elements in either half (right or left half as commonly tabulated) of a Mendelejeff group are proportional to the cube roots of the atomic weights of the elements that produce them. This is shown in Table III., each horizontal row of which shows the comparison between the observed shifts of the lines of one element, and that calculated for them from the observed shifts of the lines of another element of the same half of a Mendelejeff group. The lines of a few elements shift just half the calculated amount, and the agreement in these cases between half the calculated values and the observed is shown in Table IV.

Two metals, neodidymium and uranium, do not fit in either table. The observed shift of the neodidymium lines for twelve atmospheres and wave-length 4000 is 11, the calculated for didymium 35; the observed for uranium 9, and the calculated 43. The peculiar behavior of didymium in other respects, and the fact that it is one of the least understood of the elements, makes its behavior in the present instance of but little surprise. Not so much can be said of uranium, though it, too, is not free from peculiarities and besides its atomic weight is the highest known. The want of agreement between the calculated and observed shifts is true not only of these elements but also of carbon and boron, but in these two cases agreement could not be expected, partly because they are non-metallic while the others are metallic elements, but especially because they both belong to the first Mendelejeff series, the elements of which are in general not comparable in other respects with those of the following series. In the relation between the shifts of their lines and their atomic weights, as in other respects, it is only the elements of the series after the first that are comparable with each other. The agreement, as tabulated for beryllium, though a metal, must therefore be regarded as probably accidental.

The photographs of a few elements, arsenic, gold, antimony and especially sodium were not very good, and so it may happen that future measurements will cause some change in the values of their observed shifts.

What the above facts all mean — how to interpret them — does not appear very evident, and I have only one suggestion to make, which is, that the atoms of either half of any Mendelejeff group differ in weight because and only because they differ in size, that is, that they have the same density. If this be true and if, as seems most probable, the atoms have the same general shape, then the cube roots of their weights are to each other as their linear dimensions, and hence the shifts of the lines would be to each other as the linear dimensions of the atoms that produce them, which in turn is in perfect accord with the known facts, first — that the change in the linear dimensions of a body, due to pressure or to temperature, is proportional to its linear dimensions, and second, that the time of the elastic vibration of a body as well as that of its electric oscillation increases with increase of its linear dimensions.

On this supposition the fact that the lines of certain elements shift only half the calculated amount may be explained by assuming their atoms to dissociate in such manner that the linear dimensions of the parts are only half that of the original whole.

In closing I wish the pleasure of thanking Professor Rowland and Dr. Ames, Directors of the Physical Laboratory, for their constant interest and frequent assistance during the entire time of this investigation.

TABLE I.

Element	Pressure in Atmospheres	6	6½	6¾	7	7½	8	8½	9	9½	10	10½	11	11½	12
Sb	3267.6			21 26											
As	2898.83							20 28	18 25						
Ba	4432.13				45 41										
"	4506.11				36 32								56 50		
"	5535.69						52 38				56 40	58 42			
"	Average for group A				41 37		52 38				56 40	58 42	56 50		
"	4554.211				23 20			24 21			32 28	34 30	40 35		
"	4934.237										34 28				
"	Average for group B				23 20			24 21			33 28	34 30	40 35		
Be	3130.6					11 14									
"	3321.3					19 24									
"	3321.5					19 24									
"	Average for beryllium					16 21									
Cs	4555.45	138 121			123 108										
"	4593.34	95 82			78 68										
"	Average for caesium	117 102			101 88										
Ce	3895.224		20 21												
"	3896.917		14 14												
"	3898.4		22 23												
"	3912.5		17 17												
"	3917.7		13 13												
"	3918.4		8 8												
"	3919.9		20 20												
"	3921.6		22 22												
"	3929.3		17 17												
"	3931.2		17 17												

TABLE I.—*Continued.*

Element	Pressure in Atmospheres	6	6½	6¾	7	7½	8	8½	9	9½	10	10½	11	11½	12
Ce	3940.4		19 19												
"	3941.1		8 8												
"	3949.2						8 8								
"	3953.7		8 8												
"	3955.4		10 10												
"	3957.4						15 15								
"	3961.0		7 7												
"	3964.6		6 6												
"	3971.8		12 12												
"	3972.2		17 17												
"	3975.1		19 19												
"	3978.7		7 7				9 9								
"	3984.7		12 12												
"	3989.5		11 11												
"	3992.5		15 15				21 21								
"	3993.0		17 17												
"	Average for cerium		14 14				13 13								
Nd	4279.874								18 17						
"	4281.0								7 7						
"	4284.8								6 6						
"	4302.7								7 7						
"	4319.1								12 11						
"	4328.1								3 3						
"	4329.2								4 4						
"	4334.3								5 5						
"	4348.0								11 10						

TABLE I.—*Continued.*

Element	Pressure in Atmospheres	6	6⅓	6¾	7	7½	8	8½	9	9½	10	10½	11	11½	12
Ndi	4362.2								5 5						
"	4385.8								15 14						
"	4401.0								14 13						
"	4420.7								6 5						
"	4421.3								14 13						
"	4424.5								8 7						
"	4434 0								10 9						
"	4434.5								13 12						
"	4444.4								2 2						
"	4446.5								2 2						
"	4458.7								4 4						
"	4467.5								6 5						
"	Average for neodidymium								8 8						
Au	4041.07				20 20										
"	4065.22				34 33										
"	Average for gold				27 26										
La	3921.695								21 21						
"	3929.363						13 13		32 33						
"	3949.199						26 26		24 24						
"	3995.899						21 21		35 35						
"	4031.865						7 7		14 14						
"	4043.054						29 29								
"	4077.498						17 17								
"	4086.861						21 21								
"	Average for lanthanum						19 19		25 25						
Mg	2852.239										16 22		21 29		

TABLE I.—*Continued.*

Element	Pressure in Atmospheres	6	6½	6¾	7	7½	8	8½	9	9½	10	10½	11	11½	12
Mg	3829.501								33 34		28 29				
"	3832.450								30 31		31 32				
"	3838.435								40 41		30 31				
"	5167.497								66 51						
"	5172.856								62 48						
"	5183.791								47 36						
"	Average for magnesium								46 40		26 29		21 29		
Hg	3650.3										63 70		63 70		
"	5461.0										90 66				
"	Average for mercury										77 68		63 70		
Mo	3132.749													31 40	
"	3158.3													27 34	
"	3170.5								28 33					32 40	
"	3194.2								18 22					33 41	
"	Average for molybdenum								23 28					31 39	
Nb	3914.8									27 28					
"	3937.7									13 13					
"	4059.0							22 22		24 24					
"	4079.9							30 29		32 31					
"	Average for niobium							26 26		24 24					
K	4044.294						76 75	88 87							
"	4047.338						88 87	96 95							
"	Average for potassium						82 81	92 91							
Rb	4201.98						73 70	123 117							
"	4215.72						75 71	88 84							
"	Average for rubidium						74 71	106 101							

TABLE I.—*Continued.*

Element	Pressure in Atmospheres	6	6⅓	6⅔	7	7½	8	8½	9	9½	10	10½	11	11½	12
Si	2881.695								21 29		25 35		31 40		
"	3905.660									31 32			44 45	40 40	39 40
"	Average for silicon								21 29	31 32	25 35		38 43	40 41	39 40
Na	3302.504					13 16									
Sr	4077.885												26 26	39 38	
"	4215.703											34 32	34 32	45 43	
"	Average for group A											34 32	30 29	42 41	
"	4607.510				53 46			51 44			57 50		53 46		
Ti	3900.681							17 17							
"	3904.926							15 15							
"	3913.609							15 15							
"	3924.673							13 13							
"	3930.022							9 9							
"	3947.918							10 10							
"	3948.818							9 9							
"	3956.476							11 11						18 18	
"	3958.355								14 14					21 21	
"	3962.995							18 18							
"	3964.416							9 9							
"	3989.912								15 15					16 16	
"	3998.790												15 15	22 22	
"	4009.079							13 13							
"	4024.726							15 15							
"	Average for titanium							13 13	15 15				15 15	19 19	
W	4009.0									20 20			13 13		
"	4074.7												15 15		

TABLE I.—*Continued.*

Element	Pressure in Atmospheres	6	6½	6¾	7	7¾	8	8½	9	9½	10	10½	11	11½	12
W	Average for tungsten									20 20			14 14		
U	3886.4														12 12
“	3993.6									4 4			3 3		
“	3912.7												5 5		
“	3916.0												4 4		
“	3932.2									7 7			11 11		14 14
“	3951.5												7 7		
“	3954.9												6 6		
“	3982.6												4 4		
“	3986.0												5 5		
“	3987.6												13 13		
“	3989.7												12 12		
“	4050.3												10 10		
“	4064.6												13 13		
“	4090.4									4 4					
“	Average for uranium									5 5			8 8		13 13
V	3902.399						5 5								
“	3910.984						9 9				13 13				
“	3913.0						14 14				17 17				
“	3914.5										23 24				
“	3922.560						13 13								
“	3924.8						22 22								
“	3925.4						12 12				18 18				
“	3928.1						14 14								
“	3934.2						5 5								
“	3937.7						18 18				19 19				

TABLE I.—*Continued.*

Element	Pressure in Atmospheres	6	6½	6¾	7	7½	8	8½	9	9½	10	10½	11	11½	12
V	3938.3										20 20				
"	3939.5						26 26				23 23				
"	3950.4										15 15				
"	3979.6						17 17				17 17				
"	3984.5						16 16				15 15				
"	3984.7						21 21				24 24				
"	3980.0						12 12				22 22				
"	3990.712						22 22								
"	3992.071						15 15								
"	3998.0						14 14								
"	4042.8						17 17								
"	4051.204						16 16								
"	4051.401						10 10								
"	[illegible]						[illegible]								
"	[illegible]						[illegible]								
"	[illegible]						[illegible]								
"	[illegible]						[illegible]								
"	[illegible]						[illegible]								
"	[illegible]						[illegible]								
"	[illegible]						[illegible]								
	[illegible]						[illegible]								
	[illegible]						[illegible]				[illegible]				
	[illegible]						[illegible]				[illegible]				
	[illegible]								[illegible]						
	[illegible]								[illegible]						
	[illegible]								[illegible]						
	[illegible]								[illegible]						
	[illegible]								[illegible]						

TABLE II.

Element	S	T	$\frac{48600}{T}$
Sb	49	710	68
Ba	58 34	748	65
Be	36	>1270	< 39
Cs	161	300	162
Au	49	1310	37
Mg	46	1023	47
Hg	81	233	209
K	130	335	145
Rb	130	311	156
Na	25	369	132
Sr	65 37	>748	< 65

TABLE III.

Showing shifts in thousandths of an Ångström unit for twelve atmospheres and wave-length 4000.

Standard.		Calculated		Observed
Cs	161	Rb	139	130
Cs	161	K	109	130
Cu	33	Ag	39	39
Cu	33	Au	48	49
Cu	33	Na	24	25
Ca	54 27	Sr	70 35	65 37
Ca	54 27	Ba	81 40	58 34
Ca	54	Be	33	36
Zu	57	Cd	68	80
Zu	57	Hg	83	81
Zu	57	Mg	41	46
Al	55	In	89	88
Ti	19	Zr	23	28
Ti	19	Ce	27	27
Su	55	Pb	66	60
Su	55	Si	34	43
Bi	49	As	35	38
Bi	49	Sb	41	49
V	25	Nb	28	34
Cr	26	Mo	32	40
Co	24	Rh	29	30
Ni	28	Pd	34	33

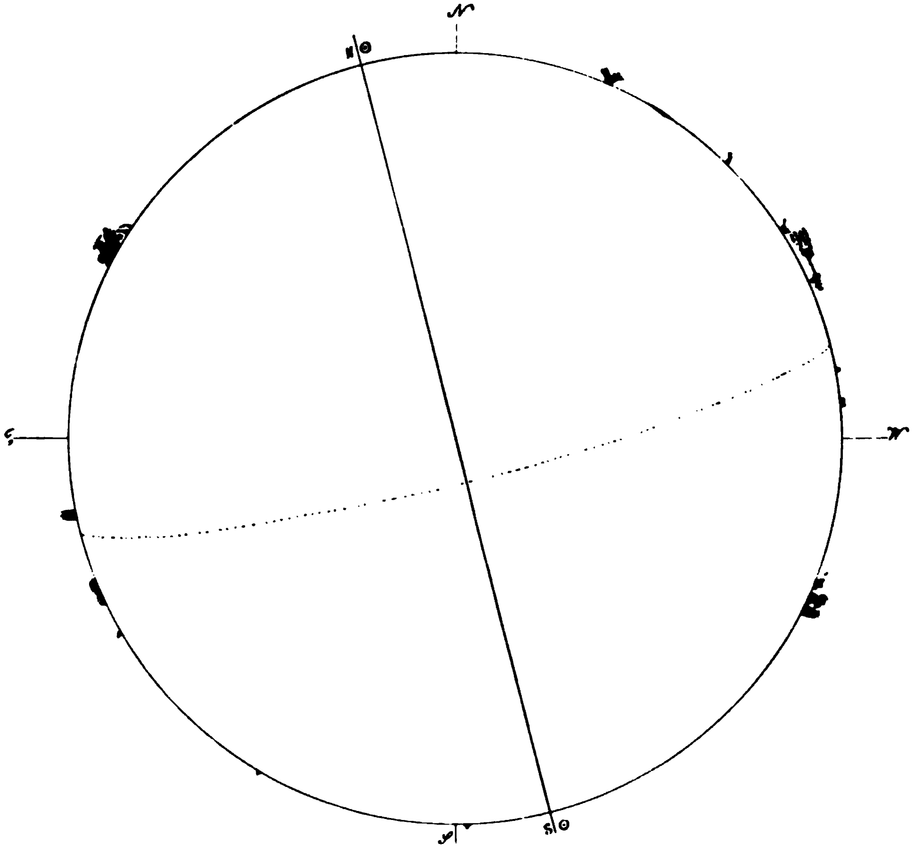
TABLE IV.

Showing shifts in thousandths of an Ångström unit for twelve atmospheres and wave-length 4000.

Standard		Calculated		Observed
La	32	Y	14	15
Al	55	Tl	54	61
Cr	26	W	20	19
Fe	25	Os	19	17
Ni	28	Pt	21	20

JOHNS HOPKINS UNIVERSITY,
October 6, 1896.

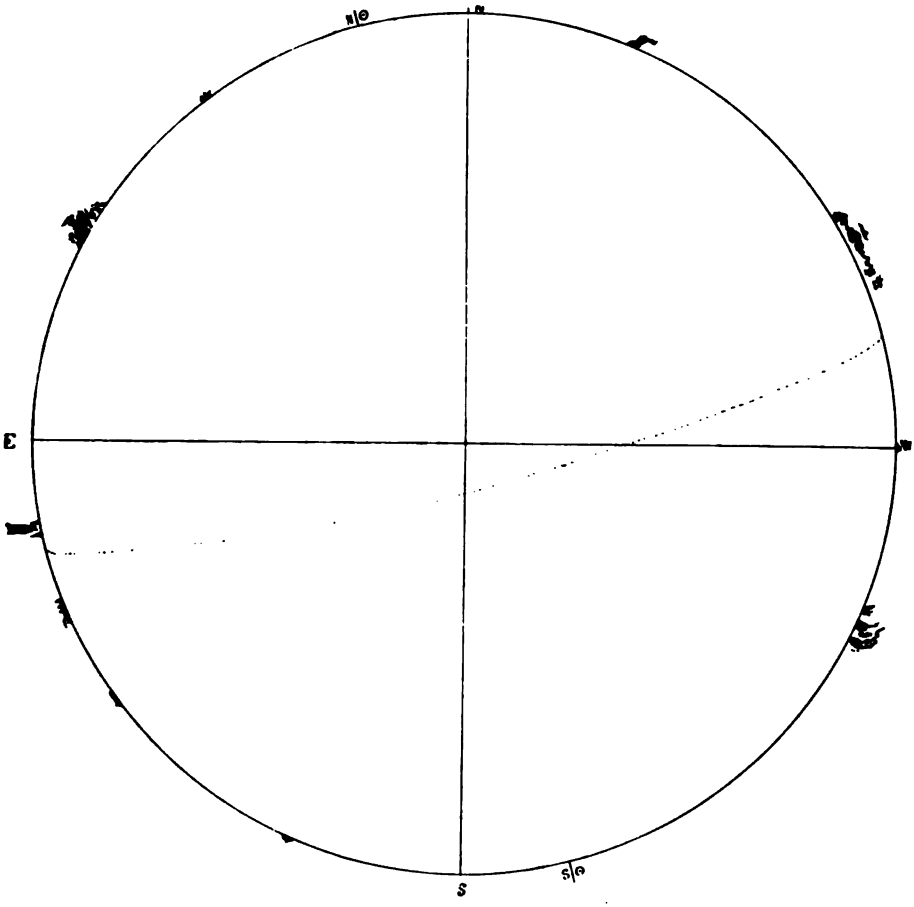
PLATE VIII.



SOLAR PROMINENCES OBSERVED BY J. FÉNYI.

1896, AUGUST 8, $19^h\ 7^m$—$22^h\ 15^m$ G. M. T.

PLATE IX.



SOLAR PROMINENCES OBSERVED BY J. FENYI.

1896, AUGUST 8, 22^h 15^m—22^h 38^m G. M. T.

PROMINENCES OBSERVED AUGUST 8, 1896.

By J. Fényi.

Soon after the end of the total eclipse the prominences were observed in Kalocsa with a large automatic spectroscope attached to the seven-inch refractor. I have communicated these observations, since they have a special interest in connection with those made during the total eclipse. Greenwich Mean Time was used.

The observations in Kalocsa began about 19^h 7^m, but after 23^m had to be discontinued on account of bad seeing. They were begun again about 22^h 40^m, in spite of the indistinct images, and ended about 22^h 15^m; at the end the image was very good; I accordingly made a second complete survey of the edge of the Sun, but found only small differences in the main features; in fact, only some small changes in elevation. The forms of the prominences, as they were observed the first time, are shown in Plate VIII.

In the following tables only those prominences are recorded which attained a height of more than 30". The positions were reckoned counter clock-wise from the pole.

FIRST OBSERVATION.

Greenwich Mean Time	Position N. to E.	Heliogr. Long.		Height in Sec. Geocentr.
		E.	W.	
21^h 45^m...............	302° 44'-293° 48'	....	+43	46"
22 8	102 10 -100 20	−26	....	49
	246 14 -243 2	....	−11	43
22 15	63 36 - 56 42	+15	....	50

SECOND OBSERVATION.

22^h 20^m...............	302° 16'-293° 36'	....	+43	42"
	246 24 -243 22	....	−11	42
22 38	102 56 -100 52	−26	....	56
22 15	63 36 - 56 42	+15	....	50

In the accompanying illustrations only the main features of the structure of the prominences can be shown on account of the small scale; but I must remark that, with a fine sky, the spectroscope at my disposal shows the prominences in such detail and sharpness that it is impossible for the delineator to represent truly all that he can see.

If the form, as observed in the spectroscope, differs from that observed at the same time during the total eclipse, the difference cannot be ascribed to the indistinctness of the image, nor to the spectroscope; this difference must be explained on the assumption that the objects though seen contemporaneously are not identical.

HAYNALD OBSERVATORY,
KALOCSA, September 1896.

NOTES ON A METHOD OF DETERMINING THE VALUE OF THE LIGHT RATIO.

By ALEXANDER W. ROBERTS.

We may define the term magnitude to mean the numerical value which we assign to the apparent brightness of a star whose light is a certain quantitative amount greater or less than that of a fixed standard light.

Thus, let x be the assumed brightness of the standard star selected, then the magnitude of a star K times brighter will be $(x-1)$, and generally

$$L_x K^{-n} = L_{(x+n)} \tag{1}$$

where L_x is the amount of light of the standard star (of magnitude x), and $L_{(x+n)}$ the light of a star whose magnitude is $(x+n)$.

This is the fundamental principle that underlies all photometric determinations of the magnitude of stars; in the first place, and directly, a comparison is secured of the amount of light of the stars whose magnitudes are to be determined, and in the second place, and indirectly, magnitudes are assigned to them by employing some value of K obtained empirically.

But the great majority of the magnitudes of stars from Ptolemy's day down to the present, has been determined without any photometric apparatus. The rapidity and accuracy with which the eye alone can determine slight differences in brightness is made use of to run a gamut of light grades from the brightest star down to the faintest visible speck. The simple expression which, in this case, determines the magnitude of a star in *grades* brighter than the standard star being

$$x - mg. \tag{2}$$

This is the general principle adopted in eye-estimates of stars, where the quantity measured is the difference in brightness between two stars, expressed in light grades.

These two methods of determining the magnitudes of stars are radically different in principle and in application—facts too often forgotten by those who argue for the special superiority of either. In photometric determinations of magnitude a difference of $5^m.0$ can be as readily determined as a difference of $0^m.5$. And herein lies the excellence of photometric measurements. In eye-estimates a difference of $0^m.5$ can often be measured with an accuracy far exceeding that possible in photometric work, but the probable error increases as the difference to be measured increases. And herein lies the weakness of eye-estimates of the magnitudes of stars. Although these last few sentences do not properly pertain to the purpose of this paper they have an indirect bearing on one portion of it.

Regarding equations (1) and (2), it is evident that they premise the accurate determination of the two constants x and K in equation (1), and x and g in equation (2), before they can be applied to the ascertainment of magnitudes. It is true that theoretically it will not matter what values are given to these constants. In photometric determinations, for example, the standard of reference, say Polaris, may be any arbitrary magnitude, and the "light ratio" K may be any constant, so long as their values remain unchanged all through the series of determinations. The magnitudes resulting from the values of x and K adopted, may, by a simple numerical operation, be related to any other values of x and K. The same holds good for eye-estimates of magnitudes; the reference magnitude x may be arbitrary and the value of a light-step arbitrary also.

Such a mode of procedure, however, would cause needless labor, and no small confusion. What is done in practice is to adopt values for the constants, K and g, that will give results in harmony with the values already determined, either visually or photometrically. When such agreement is secured we have established a relation between the two important constants K and g, or to put it otherwise, we determine the value of the "light ratio."

Hitherto the importance of this determination has been, to a great extent, dependent on the necessity to which we have referred, of securing some sort of harmony between catalogues of magnitudes obtained photometrically, and the conventional values of Argelander, Gould and Heis.

Of late, however, the advance made, both in the observation and interpretation of the variation of Algol stars, has given an additional importance to the value of the light ratio.

The variation of some stars of the Algol type is of such a nature that it is possible to deduce the orbital elements of the system from an examination of the light curve. This has been done rigorously in the case of the variables Z Herculis and R. S. Sagittarii. The relative size and brightness of the components, as well as the inclination of the system depends largely, however, upon the "light ratio" employed, if the observations have been made by eye-estimates alone. It is true that if the observations along the light curve be taken by the aid of a photometer, so that the actual decrease or increase of light measured is the absolute and final data necessary for an immediate solution of the problem, neither magnitudes nor light ratio enter into the question. And thus it would apparently seem that for the determination of the conditions of orbital movement that produce variation of the Algol type, photometrical observations are much more valuable.

This apparent advantage is somewhat minimized by the fact that observations made by any of the photometers at present used by astronomers must be always, from the nature of things, inferior to estimates by sequences, *when the variation to be measured is of narrow range*. And mainly for this reason, tha by whatever instrument the intensity of the star's light is gauged, the numerical value obtained depends solely on an eye-estimate of the apparent relative brightness of two points of light. Thus, any determination by photometry will be uncertain by at least the constant error that measures the uncertainty of any determination by eye-estimates alone. Then to this error we must add the probable errors arising from unequal polarization, or obscuration, or reflection, as the case may be.

Granting, however, a slight advantage to the method of eye-estimates by sequences, in the matter of accuracy within narrow limits, there is this decided disadvantage that such observations cannot fully be utilized for the determination of orbital movement without the application of the light ratio. If this constant were known with extreme accuracy, the arbitrary magnitudes of any observer could be transposed into absolute light values. When we consider the fact that nine-tenths of the observations of Algol stars have been made without any instrumental aid, other than an ordinary telescope, and further that for many years to come this method of securing observations of variable stars will be more in use than any other, the need for a rigorous determination of the value of the light ratio is evident enough.

The purpose of the present paper is to indicate a simple and expeditious method of determining the value of the light ratio, that, theoretically at least, is much more accurate than that usually adopted, viz., by comparison of different uranometria.

By means of reflection a star is brought into the field of the telescope, and its magnitude is carefully determined from the other stars in the field by the method of sequences. It is of importance that there should be several stars in the field differing from one another in magnitude by only a few grades, and that the magnitude of the reflected star is not brighter or fainter than these stars to be used as comparison stars. The reflected star is then superimposed upon one of the comparison stars and the resulting magnitude is carefully noted.

We thus obtain an equation of the form

$$L_x + L_{x-n} = L_{(x-m)} \tag{3}$$

x being the magnitude of the fainter of the two stars whose light is combined, $(x-n)$ the magnitude of the other star, and $(x-m)$ the magnitude of the two stars, when combined.

By equation (1)

$$L_x K^{-n} = L_{(x+n)} .$$

Therefore substituting in (3)

$$L_x + L_x K^n = L_x K^m \tag{4}$$

or taking the light of the fainter star as unity,

$$1 + K^n = K^m. \tag{5}$$

Each superposition gives, therefore, a value of the light ratio K; and these can be afterwards weighted and discussed with relation to magnitude.

As far as possible the two stars superimposed should be *nearly* of the same magnitude.

The accuracy of each of the determinations depends entirely on the accuracy with which it is possible to determine the relative magnitudes. I have elsewhere proved the possibility of reducing the average error of a single observation to at least $0^m.04$, when due precautions are taken to eliminate position error.[1] Taking, however, the average error as $0^m.05$, this gives as the theoretical error of a single determination of the value of the light ratio, by this method

$$\pm 0.12.$$

The advantages of this method are:

1. A determination of the light ratio is made simply and solely from a comparison by eye-estimates of the apparent magnitudes of a group of stars. No accessories other than two plane mirrors are required.

2. The light-ratio can be determined with relation to magnitudes. An investigation I made in 1894 and 1895, seemed to point clearly to a varying light ratio (or a varying light grade), but the data on which the determination depends are not sufficient to warrant absolute certainty. *A priori*, however, it would appear that the sensitiveness of the eye cannot be the same for all magnitudes.

3. The determination is made directly for the purpose of determining the light ratio. This is the immediate purpose of the investigation and not a secondary consideration, as is the case when different catalogues are compared.

The importance of an accurate value of the light ratio lies, as we have said, in its application to the orbital movement of Algol binaries. While investigations dealing with the size and brightness of the components of an Algol system, require an accurate knowledge of the value of the light ratio, if the investigation be based on measures taken by sequences only, it is remarkable that it is to Algol variables that we must look for perhaps the most accurate and simplest determination of this constant.

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[1] See *Ap. J.*, 4, 184.

As yet the variation of known Algol variables can only indicate a limit in one direction to the value of the light ratio, but as the number of stars of this type increases, it is extremely probable that the value will be fixed with considerable accuracy.

Thus, for example, in the case of the southern Algol variable S Velorum, there is a stationary period of about 6½ hours. During this period the star remains constantly at $9^m.25$, and we see only the larger and fainter of the two components. The normal magnitude of S Velorum is $7^m.85$. This is the combined magnitude of both stars; of the large, almost non-luminous central star, and the brighter but smaller satellite. In orbital movement of this nature there must be a secondary but very faint minimum, when the bright satellite comes *in front of* the central star.

Although this minimum can only be barely appreciable, still I think that I have been able to secure reliable observations of it. At this secondary minimum the star seems to be about $0^m.05$ lower than at the normal phase. As the length of the constant phase at primary minimum gives roughly a value of the relative areas of the two spheres, viz.:

$$18 : 106$$

we have as the determining equations for the light ratio, L_x being the magnitude of the fainter star and L_{x-y} the magnitude of the brighter but smaller star:

$$
\begin{aligned}
&L_x \quad - \quad - \quad - &&= 9^m.25 \\
&\tfrac{88}{106} L_x + L_{x-y} \quad - \quad - &&= 7\ .90 \\
&L_x + L_{x-y} \quad - \quad - &&= 7\ .85
\end{aligned}
$$

Substituting equation (1) and simplifying,

$$\tfrac{88}{106} L_x + L_x = K^y L_x K^{1.35}$$

$$L_x + L_x K^y = L_x K^{1.40}$$

therefore,

$$K^{1.40} - K^{1.35} = \tfrac{18}{106}$$

and

$$K = 2.57.$$

This star does not afford a very good example of the method of investigation, as the stars are too unequal in brightness, and an error of even $0^m.01$ in the determination of the secondary minimum will modify considerably the value of *K* obtained. Still the process will be clearly exemplified.

From four other Algol variables we obtain a definite limit in one direction to the light ratio.

The elements of the variable Z Herculis are, according to Dunér,

Mag. at max. = $6^m.89$
at 1st min. = 8 .05
at 2d min. = 7 .35

Assuming the eclipse to be central,

$$L_{8^m.05} + L_{7^m.35} = L_{6^m.89}$$

and by equation (5)

$$1 + K^{0.70} = K^{1.16}$$

therefore,

$$K = 2.51.$$

This is the maximum limit of the light ratio from Dunér's limits of variation of Z Herculis. If the eclipse is not central then the light-ratio is smaller than that obtained from a solution premising a central eclipse.

In a recent Harvard College Observatory Circular (No. 7), Professor Pickering states that, "the light curve of β Lyrae found by Argelander may be closely represented by assuming that the primary minimum is caused by the eclipse of the brighter body by the fainter, and the secondary minimum by a similar eclipse of the fainter body by the brighter."

The limits of variation of this star have been well determined, and are

Normal mag. $= 3^{m}.4$
Mag. at 1st min. $= 4\ .4$
Mag. at 2d min. $= 3\ .9$

therefore,

$$1 + K^{0.5} = K^{1.0}.$$

From which we obtain as the maximum limit of K,

$$K = 2.62.$$

The limits of the southern Algol variable R. S. Sagittarii are,

Normal magnitude $= 6^{m}.60$
Mag. at 1st min. $= 7\ .58$
Mag. at 2d min. $= 6\ .89$

There is evidence that the orbit of this interesting system does not lie exactly in the line of sight. Granting that its inclination is zero, we obtain the following equations for the determination of the maximum limit of the light ratio.

$$1 + K^{0.70} = K^{1.01}$$

From which

$$K = 3.24.$$

This value is certainly too great as there is important testimony to the slight inclination of the orbit of R. S. Sagittarii.

The limits of the new southern Algol variable X Carinae, are

Normal magnitude $= 7^{m}.90$
Mag. at 1st min. $= 8\ .65$
Mag. at 2d min. $= 8\ .62$

From which

$$1 + K^{0.03} = K^{0.75}$$

and

$$K = 2.57.$$

All the above limits of variation are obtained from eye-estimates, otherwise they could not be utilized for a determination of the greatest possible value of the light ratio. This greatest possible value, it would seem from an investigation of the limits of variation of the foregoing four stars, cannot be greater than 2.7 or 2.8.

A consideration of the variation of U Cephei and S Velorum, both Algol variable stars of the same type, points to 2.0 as the smallest possible value of the light ratio.

As the number of Algol variables increases the data for more accurate determination of the relation of intensity to apparent magnitude will also increase and we will thus be enabled to secure an independent check upon the value of this important relation obtained by a less circuitous method.

LOVEDALE, July 1896.

THE MODERN SPECTROSCOPE. XX.

ON A NEW FORM OF FLUID PRISM WITHOUT SOLID WALLS AND ITS USE IN AN OBJECTIVE SPECTROSCOPE.

By F. L. O. WADSWORTH.

IN a recent article on the Objective Spectroscope[1] by Professor Hale and the writer reference was made to the impracticability of using the ordinary form of glass prism for large apertures on account of the difficulty in securing homogeneous blocks of glass of the required size. The method of overcoming this difficulty suggested in a previous paper[2] is open to the objection (unfortunately a most serious one in most cases) that the expense of making a prism by either of the plans proposed is very considerable on account of the large number of surfaces involved, and the necessity for working the different prisms to the same refracting angle.

Unquestionably the least expensive way of making a very large prism would be to use some suitable liquid in place of glass were it not for the fact that this plan involves the use of two plates of plane parallel glass for the walls of the prism. For some time I have been engaged in an attempt to devise some plan by means of which the glass walls could be done away with, and some cheaper and at the same time efficient construction substituted. Recently a plan has suggested itself which makes it possible to dispense with the containing walls of the prism entirely, and thus not only avoid the main item of expense in its construction, but also get rid of the absorption of the glass or other material used for these parts: a point of great importance in infra-red or ultra-violet work. The plan is such a simple one that it seems hardly possible that it cannot have

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[1] *Ap. J.* 3, 54, June 1896.

[2] "Some New Designs of Combined Grating and Prismatic Spectroscopes of the Fixed-Arm Type and a new Form of Objective Prism," F. L. O. Wadsworth, *Ap. J.* 1, 245, March 1895.

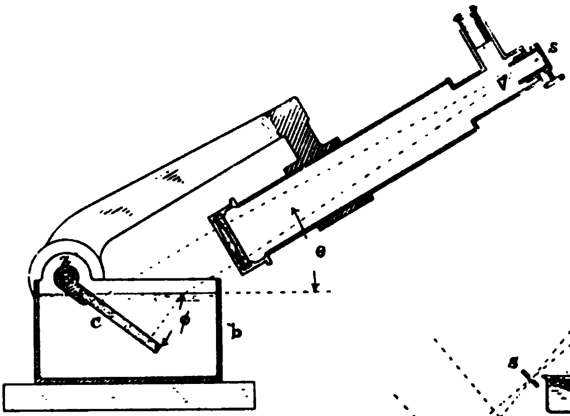

Fig. 1

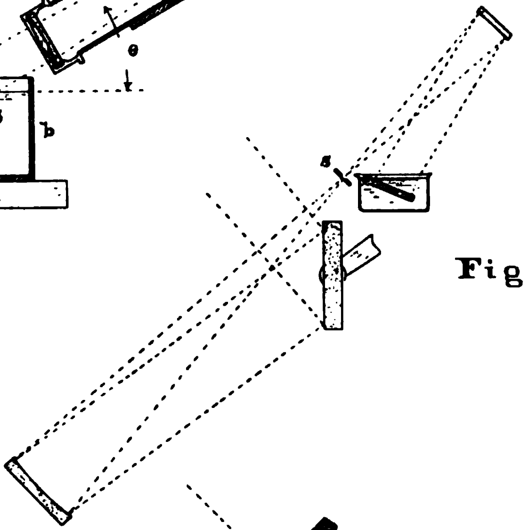

Fig 2

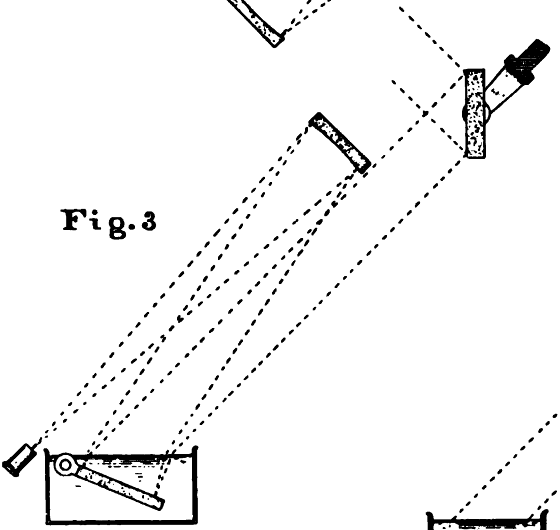

Fig. 3

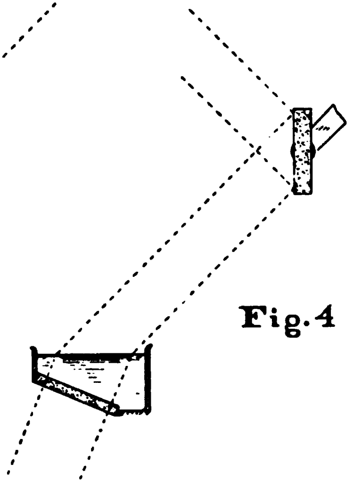

Fig. 4

A NEW FORM OF FLUID PRISM.

suggested itself to others, but as I have not been able to find any description of it published, and as it has on trial proved itself practical and convenient to use, I have thought that a brief description of it might be of interest. The general arrangement is that of a Littrow spectroscope with the axis of rotation of the instrument horizontal instead of vertical as usual. The collimated beam from the slit s (Fig. 1, Plate X.) falls on the free horizontal surface of the liquid contained in a glass or metal cell b and is there refracted. A mirror c, also movable about the axis x of the instrument, is immersed in the liquid at such an angle as to receive the refracted ray normally and reflect it back again to the observing telescope. If θ is the angle between the axis of the telescope and the surface of the liquid and ϕ the angle between the latter and the mirror face (and consequently the angle of the liquid prism), we must evidently have for minimum deviation

$$\theta = \cos^{-1} \mu \sin \phi.$$

It is evident that we may satisfy this condition in either one of two ways: (1) By fixing the axis of the telescope at any particular angle θ and moving the plate about the axis x until the angle ϕ satisfies the above relation; or (2) by fixing the mirror c in position and moving the telescope. The motion of the prism as a whole as in the ordinary spectroscope is of course not here possible.

In the first method we in reality vary the refracting angle of the prism itself. In some respects this is a decided advantage. One unique result is that the resolving power of the instrument is nearly constant for different wave-lengths. For as will be easily seen we have in this case for the resolving power r

$$r = \frac{b}{\tan \theta} \cdot \frac{\frac{d\mu}{d\lambda}}{\mu} = \text{Const.} \frac{\frac{d\mu}{d\lambda}}{\mu}$$

b being the aperture of the telescope. The resolving power therefore depends only on the ratio of $\frac{d\mu}{d\lambda}$ to μ and both of these quantities increase or decrease together.

By varying θ and adjusting as in the first case we can obtain a prism of any equivalent refracting angle desired up to the complement of the angle of total internal reflection for the liquid used.

This form of liquid prism is particularly well adapted for use in an astronomical spectroscope of either the compound or the objective type, in connection with a polar heliostat, provided the latitude of the place is not either too high or too low. In either case the heliostat is arranged to send the beam down the polar axis instead of up it as is usually done. The advantages of this arrangement were pointed out by the writer in the last number of this JOURNAL.[1] In the case of the compound spectroscope the arrangement of parts would be that indicated in Fig. 2 if mirrors were used throughout the train. If lenses were used the whole train would obviously lie in the prolongation of the polar axis.

In the case of the objective spectroscope the arrangement would necessarily have to be slightly modified so as to either use the prism out of the position of minimum deviation as in Fig. 3, (an arrangement similar to that used by Professor Hale in one of his earlier attempts to photograph the corona without an eclipse), or by substituting for the mirror *c* a plane parallel plate of glass which transmits the beam instead of reflecting it (Fig. 4). The prism then becomes in effect a fluid half prism. The expense of the lower plate would detract from its advantage on the score of first cost, although it would still be less expensive than the ordinary liquid prism with two walls, and very much less expensive than a solid prism of glass of the same size.

It is hardly necessary to remark that in order to secure the best results the whole instrument (or, if the latter be very large, the tank containing the liquid only) must be mounted in such a way as to be unaffected by vibration. This is accomplished by mounting it on a heavy slab of iron or stone supported on rubber[2] blocks, or if this is insufficient by floating it on mercury.[3] In either case it is perhaps well to point out that good results are only attained when the mass supported by the rubber or the mercury is very great; hence the necessity for using large blocks of stone or iron under the instrument itself. The principle involved is of course that no form of support will completely absorb all vibration and that the heavier the mass supported the less will it be affected by the small residue of vibration communicated to it.

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[1] *Ap. J.*, 4, 241; see also p. 310 of the present number.

[2] Ordinary cork answers nearly as well if rubber is not available.

[3] Instead of mercury heavy cylinder oil, which was suggested and used by Mr. Hoffman (see *Ap. J.*, 3, 293) as a substitute for mercury for reflecting surfaces, might be used for this purpose also.

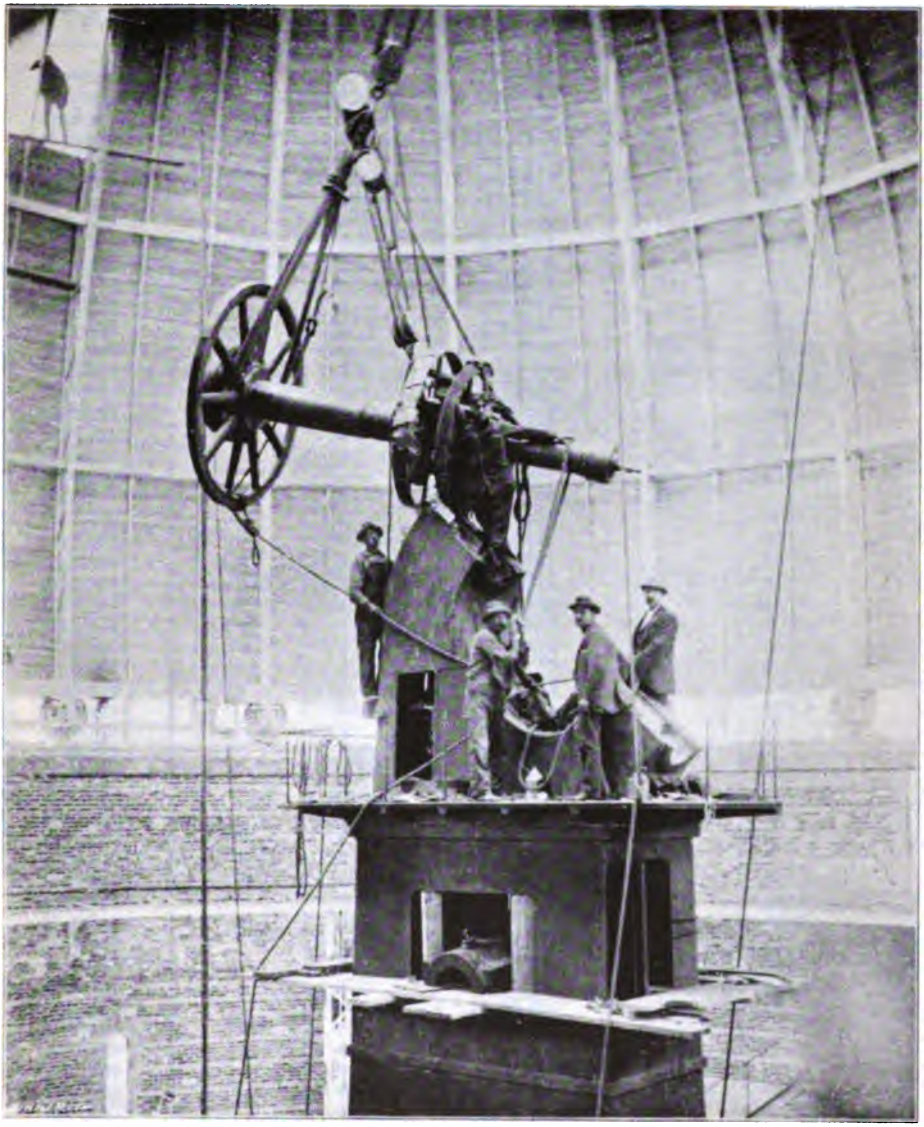
KENWOOD OBSERVATORY,
October 1896.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XV.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3133.605	Zr	0	3138.901		0
3133.790		000 N	3139.031		0
3134.080		00 Nd?	3139.221		000
3134.230 s	Ni, Fe	8	3139.279		2
3134.451		1	3139.421		0
3134.510		1	3139.601		00
3134.655		000	3139.781		1
3134.740		00	3139.876		1
3134.830		00	3140.052	Fe?, Co	5
3135.051	V,-	2	3140.131		0000
3135.160		000	3140.324		0
3135.295		000	3140.503	Fe?	2
3135.470	Fe?	1	3140.626		000
3135.567	Fe?	1	3140.872 s	Co,-	3
3135.703		0	3141.053		000 N
3135.821	Fe?	2	3141.221		00
3135.985	Fe?	1	3141.296		0
3136.130		00	3141.411		00
3136.200		000	3141.628	-,Ti?	0
3136.310		0	3141.781	Ti?	00
3136.460		00	3141.916		0000
3136.621	Fe?	2	3142.023		2
3136.705		0	3142.136		000
3136.822	Cr, Co	3	3142.271		000
3137.005		1	3142.339		0
3137.140	Zr	0	3142.585	Fe, Cu?	5
3137.215		000	3142.626		000
3137.445 s	Co	3	3142.791		000
3137.560	Co	000	3142.846	Mn	00
3137.675		00	3143.012	Fe	2
3137.825		00	3143.131		1
3137.880	Co	0	3143.271		00
3138.011		00	3143.357	Fe?	1
3138.129		00	3143.451		0000
3138.191		00	3143.601		2 N
3138.321	Cr?	000	3143.690		1 N
3138.421		0000	3143.879	Ti	4
3138.521		000	3144.011		0
3138.633	Fe?	2	3144.111	Fe	2
3138.798	Zr	1	3144.231		0

PLATE XI.



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Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3144.351		0	3150.947	Co?	0000
3144.441		0	3151.120		1
3144.568		1	3151.212		0000
3144.616	Fe?	1	3151.352		1 N
3144.744		0	3151.467	Fe	2
3144.852	Ti?	1	3151.632		0000
3144.931		000	3151.757		000
3145.040		0	3151.978	Fe?	1
3145.206	Co, Fe	3	3152.115		1
3145.251		2	3152.232		0
3145.484		3	3152.377	Ti,-	5
3145.641		0	3152.572		00
3145.840	Ni,-	2	3152.712		0000
3145.906		1	3152.852	Co,-	1 Nd?
3146.091	Zr	1	3152.972	Cr?	000
3146.221		000	3153.072		0
3146.371		1	3153.173		00
3146 416		0	3153.306	Fe	3
3146.581		0	3153.434	Fe?	1
3146.713		1	3153.683	Cr,-	00 Nd?
3146.871		0	3153.866 s	Fe?	1
3147.049		1	3153.985		0000
3147.183	Co	2	3154.120		00
3147.350	Cr	3	3154.235		00
3147.382	Ti?, Fe?	2	3154.315	Fe, Ti	3
3147.562		1	3154.535		1
3147.714	Fe?	1	3154.608	-,Fe	1
3147.899	,Fe?	1	3154.710		0
3148.157	Ti	2	3154.758	-,Co	0
3148.283	Mn	1	3154.903	-,Co	1
3148.422		00	3155.055		000 N
3148.555	Fe, Cr	3	3155.245	-,Cr	1
3148.757		0000 N	3155.405	Fe	1
3148.912		0 N	3155.520		00
3149.015		0	3155.737		0
3149.237		000 N	3155.773	Ti	3
3149.432	Co	1	3155.910	V	0
3149.512		000	3156.020		0
3149.612		00	3156.055		0
3149.757		0000	3156.205		0000
3149.839		0	3156.305		0000
3149.967		2	3156.387	Fe	2
3150.013		1	3156.565	Fe?	1
3150.192		1	3156.680		0
3150.344		0	3156.842		00
3150.422	Fe	1	3156.960		0
3150.532		00	3157.030		0
3150.627		000	3157.145	Fe	2
3150.767	Co?	0000	3157.257	Co, Fe?	1
3150.862		1	3157.408		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3157.525	Ti?,-	1	3163.336		0
3157.615		1 N	3163.536		2
3157.748		00	3163.671		0000
3157.865		0	3163.796	Cr	0000
3157.996	Fe	1	3163.881		0
3158.110	Fe?	0	3164.001	Fe	1
3158.163		0	3164.043		1
3158.305		00	3164.181		0
3158.465		0	3164.286	Cr	00
3158.517		1	3164.408	Fe?	1
3158.635		0	3164.531		0
3158.747		0	3164.661		0
3158.897	Co	1	3164.798		1
3159.000 s	Ca	2	3164.946		1
3159.125	Fe?	0	3165.011		000
3159.225		0	3165.117	Fe	1
3159.375		0	3165.196		000
3159.463		0	3165.269		1
3159.550		00	3165.378		0
3159.645		1	3165.532	Zr	00
3159.785	Co	0	3165.624		1
3159.945		00 N	3165.787		000 N
3160.049		0 N	3165.987	Fe	1
3160.196		00	3166.070	-,Zr	2
3160.327	Fe?	2	3166.242		0
3160.461	Fe	1	3166.367	Ti	1
3160.586		0000	3166.447		0
3160.726	Cr?	00	3166.550	Fe	1
3160.761	Fe	2	3166.707		0
3160.915		1	3166.786		1
3161.036		0	3166.879		0
3161.146	Mn	0	3166.977		000
3161.317	Ti	3	3167.097		00
3161.495	Fe	1	3167.289 s	Mn	1
3161.536		0	3167.407		0000
3161.666		00	3167.527		000 N
3161.766	Co	000	3167.707		00 N
3161.887	Ti	3	3167.902		1
3162.014		0	3167.971		3
3162.065	Fe	3	3168.022	Fe?	2
3162.236		0000	3168.157		0000
3162.291		0000	3168.263		2
3162.406	Fe?	1	3168.392		0000
3162.546		00	3168.547		000
3162.683	Ti	4	3168.640	Ti	4
3162.816		000	3168.784		0
3162.916		0	3168.968	Fe	1
3163.036		0000	3169.067	Fe?	1
3163.141		0000	3169.187	Co?	000
3163.208		1	3169.304	Co?,-	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3169.478		1	3175.931		0000
3169.539		1	3176.099 s	La?, Fe?	1
3169.727		0	3176.211		0000
3169.864	Co	1	3176.410		1 } d
3169.972		0	3176.462	Fe?	1 }
3170.117		0000	3176.556		00
3170.239		00	3176.711		0000
3170.367		0000	3176.786		0000
3170.455	Fe, Mo	2	3176.946		000
3170.592		00	3177.041		0000
3170.822		1	3177.191	Fe?	00
3170.917		0000	3177.413	Co	2
3171.096		0	3177.633	Fe?	2
3171.252		000	3177.791		1
3171.327		0000	3177.933		00 Nd?
3171.466	Fe	2	3178.132	Fe	2
3171.577		0000	3178.272		1
3171.776	Fe?	1	3178.437		0000
3171.882		00	3178.542		00
3172.047		000	3178.620	Mn, Fe?	1 Nd?
3172.162 } s		3	3178.752	Fe?	0000
3172.198 }	Fe?	4	3178.897		000 d
3172.408		0	3179.077	Fe	0
3172.488		0000	3179.172		00
3172.618		0	3179.277	Cr?,-	000 N
3172.758		000	3179.453	Cr?,Ca	5 d?
3172.833	Ti?	0000	3179.624	Fe	1 N
3172.963		000	3179.782		000 N
3173.108		1	3180.012		0
3173.321		0	3180.077		00
3173.519	Fe?	1	3180.232		00 N
3173.661		00	3180.347	Fe, Co	3
3173.716	Fe?	1	3180.602		0
3173.794	Fe?	1	3180.821	Cr	2
3173.951		000	3180.857	Fe	2
3174.061		000	3180.992		000
3174.166		00	3181.102		000
3174.266	Co?	0	3181.242		0000
3174.332		0	3181.312		0000
3174.491		0	3181.387	-,Ca	3
3174.601		1	3181.531	-,Cr?	0
3174.808		2	3181.642	Fe	1
3174.896		0000	3181.752		00
3175.064	Co	1	3181.856	Ni	0
3175.156	Cd?, Fe	0	3181.975	Fe?	1
3175.276		0000	3182.022	Zr	1
3175.425	Fe?	1	3182.172	-,Fe	1
3175.562	Fe	2	3182.232	Co	00
3175.666		0000	3182.357		0
3175.821		0000	3182.427		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3182.582		2	3188.656	-,Fe	6d?
3182.762		0 N	3188.934	Fe	2
3182.918	Zr	0	3189.046		000
3182.961		1	3189.196		0000
3183.101	Fe, Ni?	3	3189.281		0000
3183.235	Fe?	2	3189.429		0
3183.372	Ni?	0	3189.606		00 N
3183.428	Cr?	00	3189.746		0000
3183.533	V	1	3189.876		00
3183.631		000	3189.936	Co	000
3183.692		0	3190.076		000
3183.873		0000 N	3190.154	Fe?	1 } d
3184.075		2	3190.216		1 }
3184.109	V	2	3190.276		000
3184.225	Ti	1	3190.406		000
3184.321		0	3190.516		000
3184.490	-,Ni	2	3190.651		000
3184.553		000	3190.795	V	2
3184.658		00	3190.961	Fe?	2
3184.726	-,Fe?	1	3191.011	Ti	3
3184.873		0000	3191.236	Fe?	0
3185.006	Fe	2	3191.306		00
3185.133		1 N	3191.426	Co	000
3185.203		0000	3191.526		0
3185.333		0000 N	3191.676		0000
3185.438		2	3191.776	Fe	2
3185.499	V	2	3191.911		00
3185.675		00	3192.001		00
3185.785		0	3192.120	Ti	2
3185.915		000 N	3192.151		00
3186.090	Co,-	0	3192.306		00
3186.215		0 Nd?	3192.386	Co?	0
3186.383		00	3192.508	Fe?	0
3186.494	Co	0	3192.646		00
3186.564	Ti	1	3192.729		00
3186.745		0000	3192.836		000
3186.863	Fe	3	3192.936	Fe	2
3186.905		1	3193.029	Fe?	1 N
3187.075		00	3193.166		00
3187.175		0000	3193.346	Co, Fe	3
3187.279		0	3193.413	Fe	2
3187.419		1	3193.661		000 N
3187.667		0 Nd?	3193.846		00 N
3187.824	V	2	3193.928	Fe?	1 N
3188.010		0000	3194.091	Mo	000
3188.145 } s	Cr?	1	3194.206	Cu	0
3188.170 }	Fe?	1	3194.346		00
3188.310		0000	3194.451		0000
3188.446		0	3194.543	Fe	1
3188.487	Co	0	3194.636		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3194.698		1	3201.494		000
3194.876		000	3201.624		00
3194.961		0	3201.724	Ti	00
3195.085		00	3201.834		000 N
3195.197		0	3202.004		000
3195.252		00	3202.069		000
3195.342		00	3202.253	Ni	1
3195.517		000 N	3202.369		00
3195.705 s	Ni	2	3202.494	V	0
3195.837	Ti?,-	1	3202.651	Ti, Fe	2
3195.987		0000	3202.779		0
3196.102		0	3202.807		0
3196.218	Fe?	3	3202.934		0
3196.307	Fe?	00	3203.054		0
3196.452		000	3203.144	Co	000
3196.577		000	3203.274		0000 N
3196.682		00	3203.435		1
3196.737		00	3203.552	Ti,-	2
3196.947		0000	3203.624		000
3197.037	Fe	1	3203.724		0000
3197.085	Fe	2	3203.824		0000
3197.222	Cr, Ni	3	3203.944	Ti	1
3197.318		000	3204.092		1
3197.473		0000	3204.225		0000
3197.653	Ti, Fe?	1	3204.396		2 Nd?
3197.708		00	3204.565		00
3197.822		1 N	3204.685		0000
3197.983		0000	3204.805		0000
3198.133	V	0	3204.975	Ti?	0
3198.213	Cr?	000	3205.065		000
3198.388		0	3205.225		00
3198.599		1	3205.335		0
3198 799	-,Co	00 Nd	3205.445		00
3199.014	Fe?	000 N	3205.520	Fe	2
3199.249		0	3205.685	V	00
3199.349		0000	3205.765		000
3199.454	-,Co?	0	3205.895		00
3199.639	Fe	4	3205.950	Ti?	000
3199.774		00	3206.119		1
3199.934		0000 N	3206.225		0000
3200.034 s	Ti	2	3206.350		0
3200.249		00	3206.460	Ti ?	000
3200.407		2 Nd?	3206.605		00
3200.581	Ni, Fe	5 Nd?	3206.645		00
3200.734		000	3206.875	-,Ti?	0 Nd?
3200.903	Fe?	2	3207.055	Mn?,-	1
3201.074		1	3207.193	-,Fe?	1
3201.126		1	3207.290		00
3201.239	Fe?	0000	3207.360		00
3201.374		00	3207.525	V	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3207.675		00	3213.677		000
3207.788		1	3213.807		00
3207.823		0	3213.857		0
3208.005	Ti?	000	3214.042		000
3208.101		0	3214.143	Fe	2
3208.206		0	3214.185	Fe, Ni	2
3208.326	Cu	0000	3214.335	-,Ti	1 N
3208.464	V	1	3214.515	Fe	2
3208.586	Fe	1	3214.607		000
3208.707	Cr?,-	1	3214.727		00
3208.801		0	3214.889	Ti,-	3
3208.906		000	3214.977		000
3209.006		00	3215.142		000 N
3209.116	Ti?	0000	3215.292		1
3209.229		00	3215.317		1
3209.297	Cr,-	1	3215.467	Co?	0
3209.411	Fe	1	3215.517		1
3209.546		00	3215.707		000
3209.601		000	3215.757		000
3209.736		000	3215.827		0000
3209.786		000	3215.957		1
3209.876		0000	3216.061	Fe	2
3210.046	-,Ni	1 N	3216.162		000
3210.158		0	3216.327		0
3210.337	Fe, Co	3	3216.472		000 N
3210.564		2	3216.659		0
3210.592	Fe?	1	3216.807		1
3210.751		0	3216.928	-,Ni	0
3210.836		00	3217.040	Mn, Ti?	1 N
3210.948	Fe	2	3217.183	Ti	2
3211.056	Co?,-	000	3217.210		1
3211.176		000	3217.413		000
3211.281		00	3217.505	Fe, Cr	2
3211.321		00	3217.658		0000 N
3211.421	Cr?	000	3217.838		0000
3211.602	Fe?	1	3217.954	Ni	1
3211.746		1	3218.048	Ti	000
3211.796	Fe?	1	3218.188		00
3211.996	Fe?	1	3218.318		0000
3212.117	Fe	2	3218.389 s	Ti	2
3212.277		1	3218.563		000
3212.435		0	3218.728		00
3212.552		00	3218.798	Cr?	00
3212.657		1	3218.978		0000
3212.802		00	3219.098	Co?	000
3213.004	Mn,-	2 N	3219.260		1
3213.247	Ti	1	3219.313	Co, Ti	00
3213.423	Fe	3	3219.483		000 N
3213.517		00	3219.543		0000
3213.587		00	3219.711 s	Fe, Cr	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3219.919 s	Fe	3	3226.266	Ti	0
3220.079		0000 N	3226.342		0000
3220.259		0000Nd?	3226.462		0000
3220.426		0	3226.562		00
3220.547		0	3226.657	Cr?	00
3220.664		00	3226.854	Fe?	1 } d
3220.721		00	3226.880	-,Ti	2 }
3220.889		000	3227.007		00
3220.949		000	3227.123	Ni	1
3221.084		0000 N	3227.175	Fe?	1
3221.249		000	3227.292		0000
3221.388	Ni	1	3227.392	Cr?	0000
3221.499	Ti	00	3227.542		0000
3221.659		000	3227.612		0000
3221.773	-,Ni	2	3227.747		0000
3221.874		0000	3227.877	Fe	2 } d
3222.002		0	3227.925	Fe	2 }
3222.034	Fe?	1	3228.112		0
3222.201 s	Fe	3	3228.219	Mn	1
3222.374		000 N	3228.370	Fe	1
3222.559		000 N	3228.503		000
3222.699		000 N	3228.618		00
3222.844	Ti?	000 N	3228.735	Ti?	2
3222.970	Ti,-	4	3228.953		0
3223.059		000	3229.016	Fe?	0
3223.214		000	3229.263	Fe	2 } d
3223.378		1	3229.324	Ti, Cr	3 }
3223.479		00	3229.468		0000
3223.564		00	3229.542	Ti	2
3223.631	Ti	0	3229.704		1
3223.754		000	3229.911	Fe?	0
3223.859		000	3229.999	Tl	0
3223.962		0	3230.106	-,Fe	1
3224.154		0000 N	3230.213		0
3224.368 s	Ti,-	2	3230.323	Fe	1
3224.540		0000	3230.588		0 N
3224.600		0000 N	3230.708		00
3224.750	Co	00	3230.843	Mn,-	1
3224.882	Mn	1	3230.962		00
3225.040		0	3231.123	Fe,-	2
3225.146	Ni	1	3231.193		0000
3225.237		0000	3231.338		0000
3225.382		00	3231.442 s	Ti	2
3225.487		000	3231.588		00
3225.577		00 N	3231.703		0
3225.732	Fe?	0	3231.823	Zr	1
3225.827		000	3231.958		0000
3225.919 s	Fe	3	3232.063		00
3226.024		0	3232.193		0000
3226.143	Mn	0	3232.273		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3232.407 s	Ti	2	3239.170	Ti	7
3232.509		0000	3239.435		0
3232.664		0000 N	3239.574	Fe	3
3232.804		000 N	3239.786	Ti	2
3232.914	Ti	00	3239.966		000
3233.055	Ni	2	3240.137		0
3233.171	Fe	1	3240.239		00
3233.284	Ni?	00	3240.381		0000 N
3233.394	Cr?	00 N	3240.522	Mn	1
3233.554		0000 N	3240.616		0000
3233.654		000	3240.726	Mn	0
3233.786		00	3240.826		1
3233.879		00	3240.991		0000
3234.093	Fe	2	3241.081	Cr	000
3234.189	Zr,-	0 N	3241.168	Zr	1
3234.394		000 N	3241.256		0000
3234.469		000 N	3241.366		0000
3234.635	Ti	3	3241.509		0
3234.764	Fe, Ni	3	3241.607		0
3234.894		0000 N	3241.721		0000
3235.049		0	3241.806		00
3235.144		00	3241.936		000 N
3235.304		00	3242.125	Ti,-	8
3235.444		0	3242.226		0000 N
3235.674	Co	0	3242.395		1
3235.701	Fe?	0	3242.531		0000
3235.888	Zr	1	3242.607		0000
3235.913		0	3242.747		00
3236.050		0000	3242.827		00
3236.251	Ti	1	3242.952		000
3236.349	Fe	2	3243.132		1
3236.540		00 N	3243.189	-,Ni	6
3236.703 s	Ti	7 N	3243.332	Cu?	000
3236.905	Mn,-	1	3243.532		1
3237.040		000	3243.682	Ti?, Co	000 N
3237.154	Co	1	3243.883	-,Mn	2
3237.260		000	3243.978	Co	1
3237.350		0	3244.147		0000 N
3237.548		1 N	3244.257	Cr	0
3237.700		000	3244.317	Fe	3
3237.840	Cr	00	3244.472		0 N
3237.967	V	2 Nd?	3244.617		00
3238.155		0	3244.667		00
3238.205	Cr	0	3244.822		00 N
3238.330	Ti	000	3244.987		00
3238.435		00	3245.137		00 N
3238.635	Cr?	00	3245.257		00 N
3238.670		00	3245.397		000 N
3238.885		0	3245.517		1
3239.015		00 N	3245.662	Cr	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3245.847		0000	3252.729	Ca	0 N
3245.907		0000	3252.865	Cr	0 N
3246.104 } s		4	3253.012	Ti, Fe	5
3246.150 }	Fe	3	3253.090	Mn	4
3246.290		0000	3253.158		000
3246.429		000	3253.274		000
3246.613	Fe	2	3253.391		00 Nd?
3246.803		0000	3253.531		000
3246.889		0000	3253.684		0
3247.096	Co	4	3253.731	Fe	2
3247.311	Co	3	3253.841		0000
3247.420	Fe	1	3253.964	Fe	2 N
3247.525		0	3254.078		2
3247.688 s	Cu	10	3254.180	Mn	1 N
3247.908		0000 N	3254.314	Ti	3
3248.095		000 N	3254.381	Co	4
3248.248	Fe	1 N	3254.497	Fe	4
3248.339	Fe	3	3254.590		2
3248.442		0000	3254.881	V, Fe	5 d?
3248.589	Ni	2	3255.150		000
3248.637	Mn	0 N	3255.283		0000
3248.731		1	3255.413		000
3248.841	Ti	2	3255.617	Mn	1 N
3248.987		0000 N	3255.800		000 N
3249.147		1	3255.937		0000
3249.313	Fe	2 N	3256.021	Fe?	6
3249.497	Ti	2	3256.102		0000
3249.577	Ni	2	3256.264	Mn	3
3249.654		00	3256.382		0000 N
3249.754		00	3256.616		1 N
3249.803		0	3256.830	Fe	2
3249.980		0	3257.081		0000 N
3250.046		000	3257.223		2
3250.136	Co	1	3257.355	Fe	4
3250.270		000 N	3257.481		00
3250.514	Fe, Zr?	3 N	3257.549		2
3250.756	Fe	3 N	3257.721	Fe	4
3250.886	Ni	4	3257.944	Cr	1
3251.060		0000 N	3258.028		0
3251.273	Mn	0 N	3258.141		0
3251.375	Fe	3	3258.221	Co	0
3251.472		1 N	3258.408		0000
3251.659		0000	3258.542	Mn, Co	3
3251.732		000	3258.752		1 N
3251.805		0000	3258.904	Fe	3
3251.977	Ti	3	3259.034		0000 N
3252.057		4 d?	3259.183	Fe	3
3252.245		00	3259.357		0000 N
3252.359		0000 N	3259.494		0000 N
3252.560	Fe	4	3259.567		0000 N

RESEARCHES ON THE ARC SPECTRA OF THE METALS. III. COBALT AND NICKEL. I.[1]

By B. HASSELBERG.

IN my investigations on the spectra of the metals in the electric arc I have taken up cobalt and nickel after having completed the work on chromium and titanium.[2] The simultaneous investigation of these two metals is advisable from the fact that on account of their close relationship and the consequently inevitable presence of the one in the other as an impurity, it might be expected that both spectra would contain a large number of common lines. This supposition has been fully confirmed; but it has at the same time been found that the separation of these lines from one another has given much less difficulty than I had anticipated at the outset. For this reason also, the number of cases in which there is still room for doubt is comparatively small.

Of the older investigations in this field of spectroscopy, so far as regards cobalt, those of Kirchhoff[3] and Huggins[4] must be mentioned. In both cases the induction spark was used to produce the spectrum, and on account of this fact, particularly in the case of Kirchhoff, it was possible to observe only the principal lines. The same thing is true of Kirchhoff's observations of nickel. Since further, as at that time it could not be otherwise, the observations are given on an arbitrary scale, from which a reduction to wave-lengths cannot be accomplished with the necessary accuracy, it has not been thought desirable to include these among the determinations which accompany this paper. In this particular the investigations carried on only a short time later by Thalén[1] appear to much better advantage. It is true that these also relate to but a small number of the principal lines; but on account of the fact that these lines are based directly upon Ångström's system of wave-lengths, it is possible to reduce their wave-lengths to Rowland's system and consequently to make a reliable comparison with the corresponding values in my catalogue. The result of this comparison, as will be seen later, is similar to that which the comparison of our observations of titanium has given, viz., the Thalén determinations possess an accuracy to be found nowhere else in the spectroscopic observations of that period.

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[1] "Untersuchungen über die Spectra der Metalle im electrischen Flammenbogen III., Cobalt und Nickel." Translated from the *Kongl. Svenska Vetenskaps-Akademiens Handlingar*, **28**, No. 6, Stockholm, 1896.

[2] See this JOURNAL, **4**, 116–134, and 212–233.

[3] *Abh. d. K. Akad. d. W. Berlin*, 1861.

[4] *Phil. Trans.*, 1864, p. 139.

These investigations, when taken together with a few of the principal lines observed by Ångström and Thalén[2] in the electric arc and certain isolated observations by Schuster[3] and a few photographic determinations made by Lockyer[4] in the short region between λ3900 and λ4000, include all that have hitherto been made in the visible part of both spectra.[5] As for the ultraviolet, Cornu[6] determined the positions of a few of the principal lines of nickel in connection with his investigations on the solar spectrum; a systematic examination of the entire ultra-violet region, both for cobalt and nickel, was first published in 1888 by Liveing and Dewar.[7] In this research the wave-lengths of a considerable number of the principal lines of both spectra were directly determined with the aid of a Rowland plane grating, the constant of which was found from measurements of the deviation of the E line of the solar spectrum in connection with Ångström's wave-length of this line; and the remaining metallic lines were measured with reference to these on photographs taken with a prism spectroscope. The values thus obtained are thus based directly upon the Ångström system of wave-lengths. Reduction to the Rowland system by multiplication with the factor 1.00016 (according to Rowland), as will be shown below, brings them into very satisfactory agreement with my own.

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[1] *Nova Acta Upsal.*, III, Ser. 6, 1868.

[2] ÅNGSTRÖM, *Recherches sur le Spectre solaire*, 1868.

[3] WATTS, *Index of Spectra*, 1889.

[4] *Phil. Trans.*, 1881, p. 111.

[5] While this is being written numerous determinations of cobalt and nickel lines are being published by Rowland in his tables of solar spectrum wave-lengths. See the ASTROPHYSICAL JOURNAL for 1895–6.

[6] *Spectre normal du Soleil*, 1881.

[7] *Phil. Trans.*, 179, 1888.

Since I have given in my former paper on chromium and titanium all necessary information regarding the methods of making and measuring the spectrum photographs as well as of determining the wave-lengths, I may at once go on to the question of the elimination of foreign lines. I have already described on previous occasions the process used for this purpose, and called attention to the difficulties which up to the present time have stood in the way of obtaining results satisfactory in this particular. This is particularly true in the case of comparisons with iron, on account of the great number of lines, especially because the true spectrum of this metal, in spite of the important investigations of Kayser and Runge, cannot by any means be regarded as known. In fact, I have found the same thing to be true in connection with my measures of the spectra of chromium and titanium, viz., that the iron spectrum of Kayser and Runge is to a large extent contaminated with foreign lines, a large part of which might have been identified and removed with the greatest ease. For example, there are present numerous lines of chromium, titanium, cobalt and nickel, and, as will be shown below, all the principal lines of manganese, almost without exception, have been found Even the two aluminium lines at λ 3961.68 and λ 3944.16, which are always present in the electric arc between carbon poles, are classed as iron lines. Similar results, although probably in lesser number, will without doubt be found from a comparison with other metals. This circumstance has led me to make direct comparisons with my own photographs of the iron spectrum in the hope of effecting as reliable as possible an elimination of the iron lines from my spectra. So far as can be seen at present the number of doubtful cases still remaining is smaller than might have been expected at the outset.

COMPARISON OF THE COBALT SPECTRUM WITH PREVIOUSLY KNOWN SPECTRA OF OTHER METALS.

COBALT AND IRON.

The greater part of the iron lines found in my photographs of the cobalt spectrum were identified and removed in the first examination with the aid of simultaneous comparisons with photographs of the iron spectrum. Corresponding with the greater richness in lines of Kayser and Runge's iron spectrum, whether it be that these lines really belong to iron or, as is certainly the case in a great number of instances, to impurities, it is possible here as with chromium and titanium to detect a large number of close coincidences by comparison of our lists, the reality of which can be determined only by means of careful investigations on plates containing both spectra especially made for each individual case. In the following table are given these close coincidences together with the results of the special investigations.

Co		Fe		REMARKS
λ	i	λ	i	
3474.16	4	74.20	1	Fe missing.
76.16	1.2	76.23	1	Fe lines so weak that coincidence cannot be determined.
76.50	1.2	76.45	1	
78.02	2	77.99	2	
78.70	2	78.75	2	
85.50	3.4	85.48	3	Coincident.
89.55	4	89.55	1	Fe missing.
3502.40	4.5	02.41	1	Fe missing.
05.28	1.2	05.21	2	Divided; λ Co > λ Fe.
06.43	4	06.45	1	Fe missing.
09.97	3.4	10.00	2	Divided; λ Co < λ Fe.
10.52	3.4	10.58	3	Divided; λ Co < λ Fe.
12.77	3.4	12.84	1	Fe missing.
20.20	3	20.20	1	Fe missing.
23.00	2	23.03	1	Divided; λ Co < λ Fe.
25.97	1.2	26.03	1	Fe missing.
29.92	4.5	29.96	3	Divided; λ Co < λ Fe.
53.28	1.2	53.35	1	Fe missing.
64.25	2	64.28	1	Fe missing.
75.48	3.4	75.55	3	Divided; λ Co < λ Fe.
82.00	2	82.00	1	Divided; λ Co > λ Fe.
84.92	2	84.84	3	Divided; λ Co > λ Fe.
85.92	1.2	85.90	3	Divided; λ Co > λ Fe.
87.30	5	87.40	1	Divided.
99.27	2	99.36	1	Divided; λ Co < λ Fe.
3604.61	2	04.60	1	Coincident.
15.55	2	15.47	1	Fe line doubtful.
24.47	2	24.52	1	Coincident.
27.95	3.4	27.97	1	Fe missing.
34.85	2.3	34.86	1	Coincident. Fe line stronger than given by K. and R
36.88	2	36.79	1	Divided; λ Co > λ Fe.
37.48	1.2	37.45	1	Divided; λ Co > λ Fe.
45.36	2	45.28	1	Divided; λ Co > λ Fe.
45.60	1.2	45.69	1	Divided; λ Co < λ Fe.
49.47	3	49.50	1	Coincident. Fe line stronger than given by K. and R.
58.05	1.2	58.13	1	A weak Fe line apparently coincident. Perhaps identical with 58.13 ?
70.20	1.2	70.26	3	Divided; λ Co < λ Fe.
83.18	3.4	83.24	1	Coincident. Fe line stronger than given by K. and R.
86.63	1.2	86.71	1	Fe missing.
90.87	2	90.92	2	
93.27	2.3	93.22	1	Divided; λ Co > λ Fe.
3707.61	2	07.66	1	Fe missing.
30.61	2.3	30.59	3	Divided; λ Co > λ Fe.
32.53	3	32.60	4	Coincident. Should not Fe be 32.50 ?
40.32	1.2	40.28	1	Divided; λ Co > λ Fe.
77.65	2	77.62	2	Divided; λ Co > λ Fe.
3805.90	1.2	05.88	1	Fe trace.
16.58	2.3	16.54	3	Divided. Fe line lies between Co 16.58 and 16.46.
45.60	4.5	45.64	1	Fe trace. Belongs to Co.
50.25	1.2	50.17	5	Divided.

Co		Fe		REMARKS
λ	i	λ	i	
3878.90	2	78.88	5	Coincident.
93.44	1.2	93.53	3	Divided.
94.21	5	94.15	2	Divided; λ Co > λ Fe.
3925.32	2	25.37	1	Divided; λ Co < λ Fe.
41.01	2.3	41.04	4	Coincident.
74.86	3	74.87	1	Coincident. Belongs to Co.
75.47	1.2	75.39	1	Divided; λ Fe < λ Co.
95.44	4.5	95.40	1	Co.
4011.07	1	11.11	1	Coincident?
23.53	1.2	23.57	1	Fe missing.
30.90	3.4	30.90	4	Coincident. All belong to Mn.
33.22	3.4	33.22	4	
34.62	3	34.65	4	
40.75	1.2	40.80	3	Divided; λ Co < λ Fe.
49.42	1.2	49.46	1	Possibly divided; λ Co < λ Fe.
58.34	2.3	58.36	3	Divided; λ Co < λ Fe.
76.72	2	76.78	5	Divided; λ Co < λ Fe.
79.39	1.2	79.38	2	Belongs to Mn.
79.58	1.2	79.56	2	Belongs to Mn.
83.10	1.2	83.09	3	Belongs to Mn.
83.76	1.2	83.76	3	Belongs to Mn.
96.08	2	96.12	5	Divided; λ Fe > λ Co.
4121.47	4.5	21.56	1	Fe missing.
62.33	2.3	62.25	1	Fe missing.
71.02	2	71.05	5	Coincident? Possibly λ Co < λ Fe.
98.56	1.2	98.48	1	Divided; λ Fe > λ Co.
4220.43	1.2	20.50	3	Divided; λ Fe > λ Co.
35.46	1.2	35.46	2	Coincident. Fe line very weak. Belongs to Mn.
48.36	1.2	48.41	3	Divided; λ Fe > λ Co.
81.23	1	81.30	1	Coincident. Intensity Co line variable. Belongs to Mn.
92.40	2	92.42	2	Divided; λ Fe > λ Co.
98.15	1.2	98.22	3	Divided; λ Fe > λ Co.
4301.22	1.2	01.22	1	Fe missing.
03.37	2.3	03.31	1	Fe doubtful.
09.55	2	09.56	3	Divided; λ Fe < λ Co.
51.69	1	51.73	3	Co missing. Belongs to Fe.
57.05	2	57.00	1	Divided; λ Fe < λ Co.
60.98	1.2	60.97	1	Coincident.
73.77	3	73.73	2	Divided; λ Co > λ Fe.
75.09	2.3	75.12	1	Fe missing.
79.37	1.2	79.42	2	Fe missing.
88.02	2	88.07	3	Co v. Fe weak. Coincident?
88.53	1	88.63	1	Co missing. Fe line considerably stronger than given by K. and R.
91.08	1	91.15	3	Divided; λ Fe > λ Co.
91.70	3	91.74	1	Fe missing.
92.02	2.3	92.01	1	
4416.63	1.2	16.62	1	
21.48	2.3	21.43	1	Fe missing.
31.55	1	31.49	1	Coincident?

Co		Fe		Remarks
λ	i	λ	i	
4433.38	1	33.38	3	Co missing. Belongs to Fe.
45.21	2	45.21	1	Fe missing.
62.16	1.2	62.17	3	Co missing. Belongs to Mn.
65.95	1.2	66.02	1	Coincident?
71.96	2	72.00	1	Coincident.
77.36	1.2	77.43	1	Fe missing.
81.76	1	81.78	1	Divided ; λ Fe > λ Co.
90.24	1.2	90.25	3	Coincident. Belongs to Mn.
92.85	1	92.90	1	Fe hardly trace. Coincident? Co line perhaps a ghost.
4502.38	1.2	02.37	1	Co weak. Coincident. Belongs to Mn.
24.88	1.2	24.97	2	Fe missing.
25.97	1.2	26.05	1	Divided ; λ Fe > λ Co.
26.70	1.2	26.72	3	Divided ; λ Fe < λ Co.
28.12	2.3	28.05	1	Divided ; λ Fe < λ Co.
34.18	4	34.19	1	Fe missing.
46.14	2.3	46.19	1	Fe missing.
64.98	1.2	64.93	2	Divided ; λ Fe < λ Co.
81.76	5	81.72	3	Divided ; λ Fe < λ Co.
4629.47	4.5	29.50	1	Fe missing.
34.94	1	34.98	1	Fe missing.
51.28	1.2	51.33	3	Fe missing.
80.62	1.2	80.55	1	Divided ; λ Fe < λ Co.
98.60	3	98.56	1	Fe missing.
4709.26	1	09.24	3	
09.88	1.2	09.89	1	Coincident. Belongs to Mn.
39.28	1.2	39.32	1	Coincident. Belongs to Mn.
49.89	4.5	49.83	1	Fe trace. Probably λ Fe < λ Co.
54.23	3	54.22	3	Coincident. Belongs to Mn.
61.68	1.2	61.72	1	Co missing. Belongs to Mn.
62.54	2.3	62.54	1	Hardly a trace of Co here. Belongs to Mn.
66.03	2	66.04	1	Belongs to Mn.
66.57	2	66.62	2	Co missing on comparison plate. Belongs to Mn.
4840.41	4.5	40.48	1	Fe trace, apparently divided from Co.
55.85	1	55.86	1	Fe missing.
4942.56	1	42.57	1	Fe trace. Coincident?
68.09	1.2	68.03	1	Coincident?
5007.48	1.2	07.56	2	Divided ; λ Fe > λ Co.
13.46	1	13.54	1	Fe missing.
22.36	1.2	22.41	3	Divided ; λ Fe > λ Co.
5105.73	2	05.72	5	Coincident. Iron line unimportant.
26.37	2.3	26.37	1	Fe missing.
33.65	3	33.70	5	Divided.
42.65	1.2	42.69	2	Divided ; λ Fe > λ Co.
53.43	1.2	53.34	3	Fe missing.
5212.87	2.3	12.91	1	Fe missing.
18.42	2	18.34	1.2	Fe trace. Probably λ Fe < λ Co.
22.71	1.2	22.70	1	Fe missing.
57.81	2.3	57.83	1	Fe missing.
66.71	3	66.78	1	Divided ; λ Fe > λ Co.
68.72	2.3	68.79	1	Fe missing.

Co		Fe		REMARKS
λ	i	λ	i	
5316.96	2	16.91	1.2	Fe missing.
41.53	2	41.55	1	
44.79	1.2	44.70	1	
47.68	2	47.68	1	
53.69	3	53.59	3	Divided. Iron line unimportant.
62.96	3	62.96	1.2	Fe missing.
65.05	1	65.08	3	Perhaps divided and λ Fe > λ Co.
77.98	1	77.94	1.2	Fe missing.
83.56	1.2	83.56	6	Coincident. Belongs to Fe.
5407.74	2.3	07.80	1	Fe missing.
57.72	1	57.78	1.2	Fe missing. Belongs to Mn.

The intensities given by Kayser and Runge for the iron lines are given in the table, reduced as accurately as possible to my scale. It will be seen that of the lines which are here designated as pairs, about one third are in reality separated from each other by a small but clearly recognizable distance. A second third includes those cases in which, on my photographs of the iron spectrum, the respective lines are missing, so that no conclusion can be reached with regard to coincidence or non-coincidence. I consider myself not very far wrong in designating the greater part of them as impurities in Kayser and Runge's iron spectrum, due, in cases of exact coincidence, to cobalt, in others to some other metal. While the relative intensities in general bear out this conclusion, failures to do so on my plates may be due to a greater purity of the iron used by me or to the use of a weaker current. In addition, a number of the principal lines of manganese are found in both spectra as impurities. These manganese lines form only a part of the lines of this metal present in Kayser and Runge's iron spectrum, since a not inconsiderable number had already been stricken from my list of the cobalt lines in the first comparison with iron. These lines will appear again below in the comparison of cobalt with manganese.

Of the remaining pairs of lines, the members of which it has not been found possible to separate, the following appear to be common to both metals:

λ	i	
	Co	Fe
3485.50	3.4	3
3732.53	3	4
3941.01	2.3	4

while the following lines due to iron should be removed from the cobalt spectrum:

λ	i	
	Co	Fe
3878.90	2	5
4351.69	1	3
4433.38	1	3
5383.56	1.2	6

The following lines remain doubtful:

λ	i		λ	i		λ	i	
	Co	Fe		Co	Fe		Co	Fe
4431.55	1	1	3690.87	2	2	3476.16	1.2	1
71.96	2	1	3805.90	1.2	1	76.50	1.2	1
4942.56	1	1	4011.07	1	1	78.02	2	2
68.09	1.2	1	4360.98	1.2	1	78.70	2	2
5105.73	2	?	88.02	2	3	3604.61	2	1
5365.05	1	3	88.53	1	1	24.47	2	1

Of these lines the first, in case the coincidence can be regarded as exact, is to be stricken from the cobalt spectrum as an iron line. The same is true also of the second line in case the intensity given by Kayser and Runge is correct. I have for the present retained the line, because on my photographs of the iron spectrum it has only a very small intensity.

COBALT AND TITANIUM.

In a careful examination of the comparisons made of these spectra I have found the following lines, which with some probability may be ascribed to both metals:

λ	i	
	Co	Ti
4534.18	4	2.3
4629.47	4.5	2.3
4778.42	2.3	2.3
4928.48	3	2.3
5369.78	3	2.3

while the following lines still seem to be doubtful:

λ	i	
	Co	Ti
3609.46	1.2	1.2
13.90	1.2	2
3890.16	1.2	1.2
98.64	2	2

COBALT AND NICKEL.

As might have been expected, the number of lines having the same position in these two spectra is very great. A careful examination of the plates showing both spectra has given the results contained in the following table:

Co		Ni		Due to	REMARKS
λ	i	λ	i		
3472.70	2.3	72.68	3.4	Ni	Intensity of the Co line variable.
74.16	4	74.21	1	Co	Also Mn.
76.16	1.2	76.19	1.2		Probably foreign lines, given also by iron.
78.02	2	78.04	1		
89.55	4	89.59	1	Co	
93.11	2.3	93.10	4.5	Ni	
95.81	3.4	95.84	1	Co	
3500.99	2.3	01.00	3	Ni	Intensity of Co line variable.
02.40	4.5	02.44	1.2	Co	
02.75	3	02.76	2	Co, Ni ?	Coincident. Intensities nearly the same.
06.43	4	06.47	1.2	Co	
10.52	3.4	10.47	4		Divided, λ Ni < λ Co.
12.77	3.4	12.78	1	Co	
15.20	3	15.17	4.5	Ni	
18.48	3.4	18.47	1	Co	
19.90	2	19.90	3	Ni	
23.57	3	23.57	2	Co	
24.66	3	24.65	5	Ni	
26.96	4.5	27.00	1	Co	
28.10	1.2	28.13	2.3	Ni	
29.17	3	29.17	1	Co	
29.92	4.5	29.93	1.2	Co	
30.52	1.2	30.51	2		Belongs to Ti.
33.49	3.4	33.52	1	Co	
48.32	1.2	48.34	2.3	Ni	
66.50	3	66.50	4.5	Ni	
69.48	5	69.51	1.2	Co	
71.98	2	71.99	3.4	Ni	
75.48	3.4	75.52	1.2	Co	
77.36	1.2	77.37	1	Co, Ni ?	
87.30	5	87.32	1.2	Co	
88.06	1	88.03	2.3	Ni	
95.00	3.4	95.00	1	Co	
97.83	2	97.84	3.4	Ni	
99.27	2	99.27	2	Co, Ni	
3602.43	1.2	02.41	2.3	Ni	
09.46	1.2	09.44	2.3	Ni	Also in Ti, but should probably be stricken from it.
10.62	2	10.60	4	Ni	
12.90	2	12.86	3.4	Ni	
13.90	1.2	13.90	1.2		Impurity line; also in Ti.
19.54	4	19.52	5	Co, Ni	
24.88	1.2	24.87	3	Ni	
27.95	3.4	27.93	1	Co	
64.25	1.2	64.24	3	Ni	
69.42	1	69.38	2	Ni	
70.58	1.2	70.57	2.3	Ni	
74.30	1.2	74.28	3.4	Ni	
88.56	1.2	88.58	2.3	Ni	
3704.17	3	04.17	1	Co	
36.96	1.2	36.94	3.4	Ni	
39.38	1	39.36	2.3	Ni	

Co		Ni		Due to	REMARKS
λ	i	λ	i		
3755.59	2.3	55.58	1	Co	
75.70	2	75.71	4.5	Ni	
83.65	2.3	83.67	4	Ni	
3807.26	2	07.30	4	Ni	
31.83	1.2	31.82	3	Ni	
32.02	1.2	32.02	2	Ni ?	
42.20	3.4	42.18	1.2	Co	
45.60	4.5	45.58	2.3	Co	
58.42	2.3	58.40	4.5	Ni	
61.30	3	61.28	2	Co	
73.26	4.5	73.25	2.3	Co	
74.11	3.4	74.08	2	Co	
76.99	3	76.96	1.2	Co	
82.04	3.4	82.02	2	Co	
84.76	2.3	84.75	1.2	Co	
85.40	2	85.45	1	Co	
94.21	5	94.20	2.3	Co	
95.12	3.4	95.10	2	Co	
3906.42	3	06.45	1	Co	
10.08	3.4	10.07	1.2	Co	
36.12	4	36.13	2.3	Co	Intensity of the nickel lines variable.
41.01	2.3	41.02	1.2	Co	
41.87	3	41.88	2	Co	
45.47	3	45.48	1.2	Co	
53.05	3.4	53.07	2	Co	
58.06	3	58.07	1.2	Co	
69.24	2.3	69.29	1.2	Co	
74.86	3	74.83	2		Independent of each other.
78.79	3	78.81	1.2	Co	
79.64	3	79.67	1.2	Co	
87.25	2	87.26	1		
95.44	4.5	95.45	3.4	Co, Ni	
98.03	4	98.07	2.3	Co	
4014.11	2	14.11	1		Common impurity.
21.04	3.4	21.03	1.2	Co	
27.20	3	27.20	1.2	Co	
41.48	2	41.52	2		Coincident. Belongs to Mn.
45.52	4	45.54	2.3	Co	
48.88	1.2	48.87	1		Coincident. Belongs to Mn.
55.69	1.2	55.68	1.2		Coincident. Belongs to Mn.
58.34	2.3	58.36	1	Co	
66.50	3	66.53	2	Co	
68.70	3	68.70	1	Co	
86.47	3.4	86.47	1	Co	
92.55	4	92.55	2	Co	
4110.69	4	10.67	1.2	Co	
18.92	4.5	18.94	2.3	Co	
21.47	4.5	21.48	3	Co, Ni	
50.59	2	50.55	1.2		Divided. λ Co > λ Ni.
4252.46	3	52.46	1	Co	
54.49	2.3	54.50	2		Belongs to Cr.
75.00	2.3	74.94	1		Belongs to Cr.

Co λ	Co i	Ni λ	Ni i	Due to	Remarks
4289.90	2.3	89.90	1		Belongs to Cr.
4331.78	1	31.78	3	Ni	
4401.71	2	01.70	4.5	Ni	
51.77	1.2	51.73	1.2		Belongs to Mn.
59.21	2	59.21	4.5	Ni	
62.60	1.2	62.59	4	Ni	
69.72	4	69.71	1	Co	
70.61	1.2	70.61	4	Ni	
4531.14	5	31.19	2	Co	
34.18	4	34.21	1	Co	
43.99	3.4	44.00	1	Co	
47.06	1.2	47.15	3		Divided; λ Ni > λ Co.
49.80	4	49.85	1	Co	
65.74	4.5	65.78	1.2	Co	
81.76	5	81.79	1	Co	
92.68	1.2	92.69	3.4	Ni	
4600.55	1	00.51	3	Ni	
05.15	2	05.15	4	Ni	
29.47	4.5	29.50	1	Co	
48.83	2	48.82	3	Ni	
68.04	1.2	67.96	2		Divided; λ Ni < λ Co.
86.38	1	86.39	2.3	Ni	
98.60	3	98.58	1.2	Co	
4701.70	1	01.72	2	Ni	
14.58	2.3	14.59	4.5	Ni	
15.93	1.2	15.93	3	Ni	
28.14	3	28.06	1		Divided; λ Ni < λ Co.
54.59	3	54.60	1	Co	
83.60	3	83.53	1		Belongs to Mn. Intensity in Co spectrum too great.
86.73	2	86.66	3	Ni	
4807.10	1	07.17	2	Ni	
13.68	4.5	13.64	1	Co	
16.12	2	16.05	1	Co	
23.70	3	23.67	1		Belongs to Mn. Intensity in Co spectrum too great.
29.19	1	29.18	3	Ni	
31.31	1	31.30	2.3	Ni	
43.60	2.3	43.66	1	Co	
55.59	1	55.57	3	Ni	
66.45	1.2	66.42	3.4	Ni	
73.65	1	73.60	3	Ni	
87.19	2	87.16	1.2		Coincident? Perhaps λ Ni < λ Co.
4918.54	1	18.53	2.3	Ni	
36.01	1	36.02	2	Ni	
53.37	2	53.34	1.2		Coincident.
84.32	1.2	84.30	3.4	Ni	
5017.72	1.2	17.75	3.4	Ni	
35.56	1.2	35.55	5	Ni	
80.70	1.2	80.70	5	Ni	
81.31	1.2	81.30	5	Ni	
5115.56	1	15.55	4	Ni	
37.28	1	37.23	4	Ni	
5453.60	1	53.56	1		Probably divided, λ Co > λ Ni.
83.56	4	83.63	1	Co	Possibly λ Co < λ Ni.

From the fifth column, which gives the origin of the lines as determined from the relative intensities, it is evident that in this particular there is still uncertainty in only the few following cases:

λ	i	
	Co	Ni
3577.36	1.2	1
99.27	2	2
3832.02	1.2	2
3987.26	2	1
4014.11	2	1
4887.19	2	1.2
4953.37	2	1.2
5433.60	1	1

The following lines may be regarded as belonging to both metals:

λ	i	
	Co	Ni
3502.75	2.3	2
3619.54	4	5
3995.44	4.5	3.4
4121.47	4.5	3

Finally, if we compare in the above lists the number of nickel lines observed in cobalt with the number of cobalt lines present in nickel, we find the numbers 58 and 67 respectively. In view of the considerably greater number of lines in the cobalt spectrum, it seems to follow that the sample of nickel used was less contaminated with cobalt than was the sample of cobalt with nickel.

COBALT AND MANGANESE.

In order to eliminate from my photographs as many as possible of the manganese lines present I investigated the spectrum of this metal simultaneously with that of cobalt. Since "Braunstein" proved itself to be poorly adapted for this purpose, I obtained from Baron Nordenskiöld some "Manganosit," a mineral which contains about 98 per cent. of manganese together with only a small portion of iron, calcium, and magnesium. When placed in the electric arc this gives a brilliant and long-enduring manganese spectrum. The following table contains the manganese lines found on my photographs of cobalt:

Co		Mn		Due to	Remarks	Fe according to K. & R.
λ	i	λ	i			
3474.16	4	74.20	2.3	Co	Intensity of the Mn line variable.	74.20
3599.27	2	99.30	1	Co		
3608.50	1.2	08.62	3		Divided.	
15.55	2	15.53	1	Co		
84.62	2.3	84.70	1	Co		
3774.72	2	74.81	1		Divided, λ Co < λ Mn.	
3845.60	4.5	45.58	1.2	Co		45.64
60.56	2	60.59	1		Coincident. Both lines weak. Common impurity?	
73.26	4.5	73.23	1.2	Co		
74.11	3.4	74.08	1.2	Co		
94.21	5	94.21	1.2	Co		94.15
3953.05	3.4	53.00	2		Divided, λ Co > λ Mn.	
91.68	2	91.75	1	Co		
95.44	4.5	95.46	1	Co		95.40
4030.90	3.4	30.90	10	Mn		30.90
33.21	3.4	33.20	10	Mn		33.22
34.62	3	34.60	10	Mn		34.65
41.48	2	41.49	5	Mn		41.50
48.88	1.2	48.88	4	Mn		48.88
55.69	1.2	55.68	4.5	Mn		55.69
61.90	1.2	61.88	3	Mn		
79.39	1.2	79.35	4.5	Mn		79.38
79.58	1.2	79.56	4.5	Mn		79.56
83.10	1.2	83.09	4.5	Mn		83.09
83.76	1.2	83.75	4.5	Mn		83.76
92.55	4	92.55	1.2	Co		92.49
4122.42	2	22.53	1.2	Co	Traces in Mn. Belongs to Co.	
4235.30	1.2	35.28	3	Mn		
35.46	1.2	35.45	3	Mn		35.47
57.80	1.2	57.80	3	Mn		57.86
66.04	1.2	66.08	3	Mn		66.15
81.23	1	81.27	3	Mn		81.30
4375.09	2.3	75.10	2		Coincident.	75.12
4451.77	1.2	51.75	3.4	Mn		51.77
57.24	1	57.22	3	Mn		57.24
57.74	1.2	57.71	3	Mn		57.74
58.48	2	58.43	3.4	Mn		58.41
61.25	1	61.25	3.4	Mn		
62.16	1.2	62.17	4	Mn		62.17
90.24	1.2	90.28	3.4	Mn	Co line weak.	90.25
99.07	1	99.06	3.4	Mn	Co line missing.	99.09
4502.38	1.2	02.38	3.4	Mn	Co line missing.	02.37
4709.88	1.2	09.87	3.4	Mn	Co line weak.	09.89
27.55	1.2	27.63	3.4	Mn	Co line missing.	27.62
39.28	1.2	39.27	3	Mn	Co line missing on comparison plate.	39.32
54.23	3	54.23	5	Mn		54.22
61.68	1.2	61.68	3.4	Mn		61.72
62.54	2	62.54	4	Mn		62.54
66.03	2	66.02	3.4	Mn		66.04
66.57	2	66.58	3.4	Mn		66.62

Co		Mn		Due to	Remarks	Fe according to K. & R.
λ	i	λ	i			
83.60	3	83.60	5	Mn		83.62
4823.68	3	23.71	5	Mn	Intensity of the Co line variable.	23.69
62.29	1.2	62.28	2.3		Divided, λ Co $>$ λ Mn.	
5149.32	1.2	49.40	1.2		Coincident.	
5413.97	1.2	13.94	2.3	Mn		
57.72	1	57.71	2	Mn		
5517.00	1	17.05	3.4	Mn	Missing in Co.	

As appears from the fifth and sixth columns, which contain the result of an examination of the photographs of both spectra, the greater part of these lines observed in cobalt are undoubtedly due to the presence of manganese as an impurity. The contrary is true only in a few cases in the ultra-violet. The following are the only doubtful pairs, the origin of which has not been determined up to the present time:

λ	i	
	Co	Mn
3860.56	2	1
4375.09	2.3	2
5149.32	1.2	1.2

I have already called attention to the fact that the iron spectrum of Kayser and Runge contains many lines due to foreign metals, and that among others the principal lines of manganese are almost without exception ascribed to iron. A glance at the last column of the above table is sufficient to prove this. I regard it as not improbable that a searching investigation of manganese, which is to be made later, will still further increase this list. It is undoubtedly true—and I am the first to acknowledge it—that the formation of the spectrum of any substance, absolutely free from all foreign lines, is a task, the solution of which appears at present unattainable, and perhaps will always remain so. But on the other hand some weight cannot be denied to the opinion that Kayser and Runge's representation of the iron spectrum will possess an importance corresponding with the remarkable accuracy of the measures only when there have been removed from it at least those foreign lines which, like those mentioned above, are immediately obvious. It will be found that such an approximate purification of the spectrum will give no special difficulty.

COBALT AND CHROMIUM.

From repeated investigations of the photographs showing both these spectra, I have found the following cases, in which the origin of the lines is doubtful or may perhaps be ascribed to a third metal:

λ	i	
	Co	Cr
3552.85	2	2
3978.80	1.2	2
4027.21	1.2	2
4564.35	2	2
4697.19	1.2	2
5370.60	1	1.2

The following lines, which either exactly coincide or are only doubtfully separated on the photographs showing both spectra, must for the present be ascribed to both metals:

λ	i	
	Co	Cr
3575.06	3	2
3641.95	2.3	3
3894.21	5	3
3969.25	2.3	2
91.82	2	2.3
4546.14	2.3	4
4698.60	3	3

Of these lines the third, fourth, and last coincide exactly in both spectra, while for the remainder there is probably an extremely small difference in position.[1]

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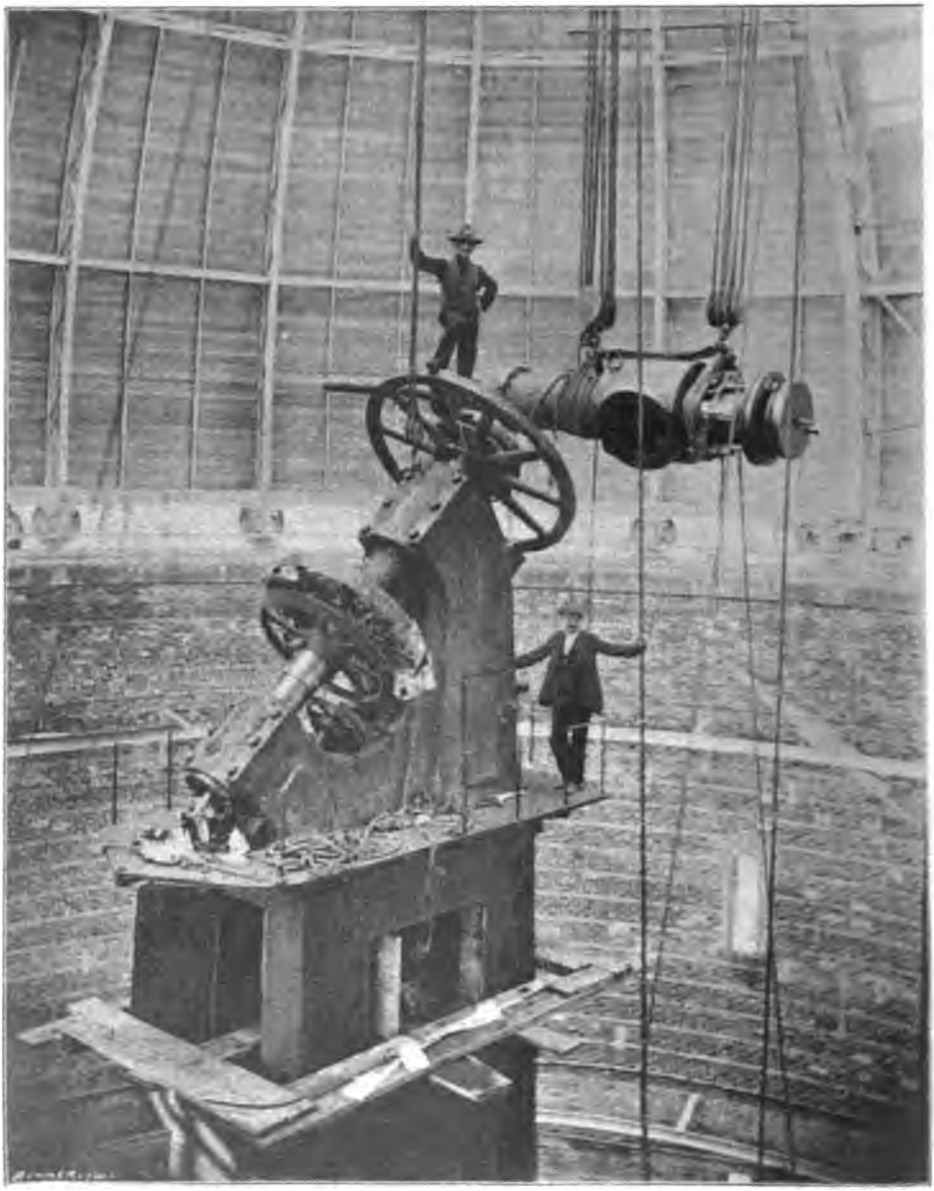
[1] In my catalogue of the chromium spectrum the two lines λ4754.10 and λ4543.99 are to be stricken out, as they are probably due to cobalt.

[*To be continued.*]

PLATE XII.



ERECTING THE DECLINATION AXIS OF THE YERKES TELESCOPE.

MINOR CONTRIBUTIONS AND NOTES.

EYE-ESTIMATES OF STELLAR MAGNITUDE.

In the article by Mr. Roberts entitled "Certain Considerations concerning the Accuracy of Eye-Estimates of Magnitude by the Method of Sequences" (Astrophysical Journal 4, 184), my views regarding visual observations of the light of the stars are so entirely misinterpreted that a contradiction seems necessary. The statement of Mr. Roberts would be nearly correct if exactly reversed, and if he should say that I do *not* consider "that determinations of variation by Argelander's method are usually inaccurate, generally uncertain, and always insufficient for important lines of investigation." The best evidence of my appreciation of Argelander's method is that for the last ten years we have used it here continuously, and several of our observers now use it every clear night in visual observations. A large part of our photographic magnitudes are also determined by this method. My only criticisms are three which I had supposed were universally admitted. First, that visual estimates cannot give the true ratio of the light of one star to that of another without the aid of some form of photometer. The same objection, of course, applies to all estimates as compared with measures, as in the case of distances, weights, or times. This objection, in the present case, is partly or wholly overcome by the use of photometric magnitudes of the comparison stars in reducing the observations. Second, that in repeated observations, that is, when one observation is made immediately after another, an estimate will not be independent if, as would usually happen, the observer recollected his previous estimate. Mr. Roberts avoids this difficulty by making his estimates at intervals of twenty minutes or half an hour. When the star varies slowly we use here still longer intervals between our estimates, while with a photometer several independent measures may be made in a minute. Third, that the subjective errors, such as those due to the position of the stars and the proximity of bright stars, are large. I am open to conviction as to whether they are completely eliminated by the methods in use here and elsewhere. I had supposed, perhaps erroneously, that they rendered it difficult to determine the character of small variations. See also an article entitled "Photometric Light Curves of U Cephei and S Antliae," sent to the *Astronomische Nachrichten* August 7, 1896.

On the other hand I fully appreciate the value of the excellent observations described by Mr. Roberts and regret that his article should be marred by matter of a controversial nature.

I shall continue to urge upon astronomers the importance of making observations by the method of Argelander, especially in the case of stars too faint to be within the reach of small telescopes.

EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY,
October 19, 1896.

ON THE MODE OF PRINTING TABLES OF WAVE-LENGTHS.

IN an article recently published in the ASTROPHYSICAL JOURNAL Professor Kayser stated that in his opinion the decision of the Editorial Board to print tables of wave-lengths with the shorter wave-lengths at the top was an ill-advised one.

During Professor Kayser's recent visit to Chicago the opportunity was offered for discussing this question, and as a result of this discussion he was requested to prepare a statement giving his views on the matter. A translation of this statement follows:

"The Editors of the ASTROPHYSICAL JOURNAL having decided to publish tables of wave-lengths beginning always with the shorter waves, I take the liberty of offering you my reasons for thinking that this is *not* perhaps the most advisable plan.

"In general it might appear to be a matter of indifference in which direction the tables run: but I think the following considerations should have weight:

"(1) *Historical development.*—Fraunhofer began his tables with the long wave-lengths, as is shown by his drawing of the solar lines between A and H.

"Ångström, Cornu, and most spectroscopists have followed his example.

"(2) One would naturally wish the tables so arranged that any additions to our present knowledge of spectra might be easily incorporated. This extension of knowledge will, of course, occur *both* in the direction of the ultra-violet and the infra-red. However, the experimental fact is that there are exceedingly few lines in the infra-red; and in the case of most elements none at all. While, on the other hand, the work of Schumann has shown that the ultra-violet is a region probably crowded with yet undiscovered lines.

"But the relative importance of the ultra-violet region is especially manifest when we come to map spectra in terms *not* of wave-lengths, but of wave-numbers.

"And that this is the best adapted of all modes of representation is shown by all the laws hitherto discovered concerning the distribution of lines.

"Let us assume, for the moment, that the infra-red spectrum may be studied between wave-lengths 20000 tenth-meters and 8000 tenth-meters. Say that the spectrum as known at present covers the region between 8000 tenth-meters and 2000 tenth-meters, and that the ultra-violet may yet be investigated between 2000 tenth-meters and 1000 tenth-meters. Now imagine these three regions plotted in terms of frequencies: the ground they cover will be as follows: 50–125, 125–500, 500–1000. That is to say, while the new infra-red region is almost insignificant, the new ultra-violet is larger than all the others put together, including all hitherto known. So that, from this point of view also, it would appear that we should begin with the long wave-lengths.

"(3) The following consideration is to my mind the all-important one, the one which leaves us no choice in the matter:

"For a large number of elements, it has already been shown that their spectra are built up with a definite structure. And time will doubtless show this to be true of *all* elements. These spectra consist of series such that when one substitutes for the variable (in the equation which represents the whole series) the smallest possible whole number, he obtains a line which is at once the longest and strongest in the whole series, the fundamental tone, so to speak. The other lines, the overtones, diminish in intensity toward the violet and finally disappear.

"If, therefore, we consider the regular structure of these spectra—and this structure is becoming daily of more importance—the only logical course would appear to be that in which the long wave-lengths are placed first.

"*All* considerations, indeed, appear to suggest this arrangement: and none, so far as I see, favor the reverse.

"In view of these facts, may it not be wise for the Editorial Board to reconsider its former decision?

"H. Kayser."

This communication was read at the third annual meeting of the Board of Editors of the Astrophysical Journal, held at Princeton University on October 15 and 16, 1896. In the discussion which followed the greater part of the members present seemed to favor Professor Kayser's view. It was pointed out that when the question was considered at the meeting of 1894 the action of the Board was in large part due to the fact that Professor Rowland had previously adopted the plan of placing the red end of the spectrum maps to the right and the short wave-lengths at the top of the table. Various objections had been urged against this plan, one of them involving this very question of the order of lines in series, and the awkwardness of reading from right to left the Greek letters which designate the hydrogen lines. But it was felt that as there are certain series which run in the other direction the decision must be to some extent an arbitrary one. It was considered to be a point of great practical importance that the maps and wave-length tables to be printed in the Journal should correspond with the standard map and tables of the solar spectrum issued by Rowland, and used by all spectroscopists. As the importance of this conclusion has increased rather than diminished during the two years which have elapsed since the question was first discussed, on account of the adoption of this procedure by the members of the Board of Editors and others in various printed works, and especially because of the publication in this Journal of Rowland's extensive wave-length tables, it was felt that no change should be hastily made. It was finally resolved to invite all who are interested in the matter to discuss it in these pages, in order that any further action which may be needed may be based on the opinion of the majority of spectroscopists. Expressions of opinion are therefore solicited for publication.

NOTE ON THE PREPARATION OF PHOSPHORESCENT BARIUM SULPHIDE.

In some recent experiments with phosphorographic plates, the writer had occasion to use some pure barium sulphide. As this could not at the time be obtained from any of the Chicago firms dealing in chemicals I decided to prepare it for myself.

Solutions of pure barium sulphide ($Ba\,Cl_2$) and sodium hydrate ($Na(OH)$) were mixed in molecular proportions so as to obtain barium hydrate ($Ba(OH)_2$), and sodium chloride ($Na\,Cl$). Hydrogen sulphide gas prepared and washed in the usual manner was then passed through the concentrated solution, throwing down the barium sulphide as a flocculent sparingly soluble precipitate, leaving only sodium chloride in solution. The complete reaction is

$$Ba\,Cl_2 + 2\,Na\,(OH) + H_2S = Ba\,S + 2\,Na\,Cl + 2\,H_2O.$$

The precipitate was collected on a filter, sparingly washed with cold water, and thoroughly dried in a steam bath. Although barium sulphide is, as is well known, ordinarily strongly phosphorescent, it showed, when prepared in this way, only the faintest traces of phosphorescence even after exposure to bright sunlight for several hours. Somewhat nonplussed by this discovery, of which I could find no mention in any of the works on chemistry which I consulted, I determined to try some of the same material prepared in the ordinary way (by fusing together barium carbonate and sulphur). This, although not as strongly luminous as the powdered blende (perhaps because of impurities), was fairly satisfactory. It then occurred to me that the phosphorescent property might be due to the action of the high heat employed in the dry process of preparation, and that the precipitated material might similarly be rendered luminous by heating. An experiment with a small fragment of the dried precipitate which was placed in a small porcelain crucible and heated over a gas blowpipe, showed this to be the case.

The power of phosphorescing depended to some degree on the degree of heat applied and the length of the heating.

These experiments are of interest as indicating that barium sulphide may exist in two molecular states, chemically identical but physically different. It will be interesting to determine whether this change is accompanied by corresponding changes in other physical properties as in the case of fluorspar, lepidolite, and some other substances which become phosphorescent when only moderately heated.

As soon as time permits further experiments will be made on this and other interesting questions which have presented themselves.

F. L. O. WADSWORTH.

NOTE ON A COMBINED EQUATORIAL TELESCOPE AND POLAR HELIOSTAT.

SINCE my review of Dr. Stoney's article was written last month (ASTROPHYSICAL JOURNAL, 4, 238) I have learned through Professor Young that the plan there proposed of combining an equatorial telescope and polar heliostat was used some years ago by Professor Langley at the Allegheny Observatory. While the plan is so simple that I hardly supposed it could be wholly new, I did not at the time of writing know that it had actually been used. I am very glad to find that the plan has the endorsement of practical use by such a well-known astrophysicist as Professor Langley. F. L. O. WADSWORTH.

A CORRECTION.

I AM very sorry to note that . . . . one error occurs in my article on the "Solar Rotation."[1] Equation (9*a*) page 103, which gives

$$P = cT(1 + \log\rho).$$

is wrong, and consequently also equation (10). This does not at all affect the validity of that which follows, since these equations are not used. Equation (10) ought to be

$$4\pi\rho + c\Delta T + cT\Delta\log\rho + \frac{c}{\rho}\left.\frac{\delta T}{\delta x}\cdot\frac{\delta\rho}{\delta x} + \frac{\delta T}{\delta y}\cdot\frac{\delta\rho}{\delta y} + \frac{\delta T}{\delta z}\cdot\frac{\delta\rho}{\delta z}\right)$$

$$= 2\omega^2 + r\frac{d\omega^2}{dr}$$

E. J. WILCZYNSKI.

BERLIN, September 28, 1896.

CHANGE OF ADDRESS.

I WISH to call attention to the fact that the instruments and apparatus of the Kenwood Observatory have been permanently removed to the Yerkes Observatory. Hereafter all communications intended for the ASTROPHYSICAL JOURNAL, the Kenwood Observatory, the Yerkes Observatory, for Professor E. E. Barnard, Professor F. L. O. Wadsworth, or for the writer, should be addressed to the *Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* GEORGE E. HALE.

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[1] *Ap. J.*, 4, 101, August 1896.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

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NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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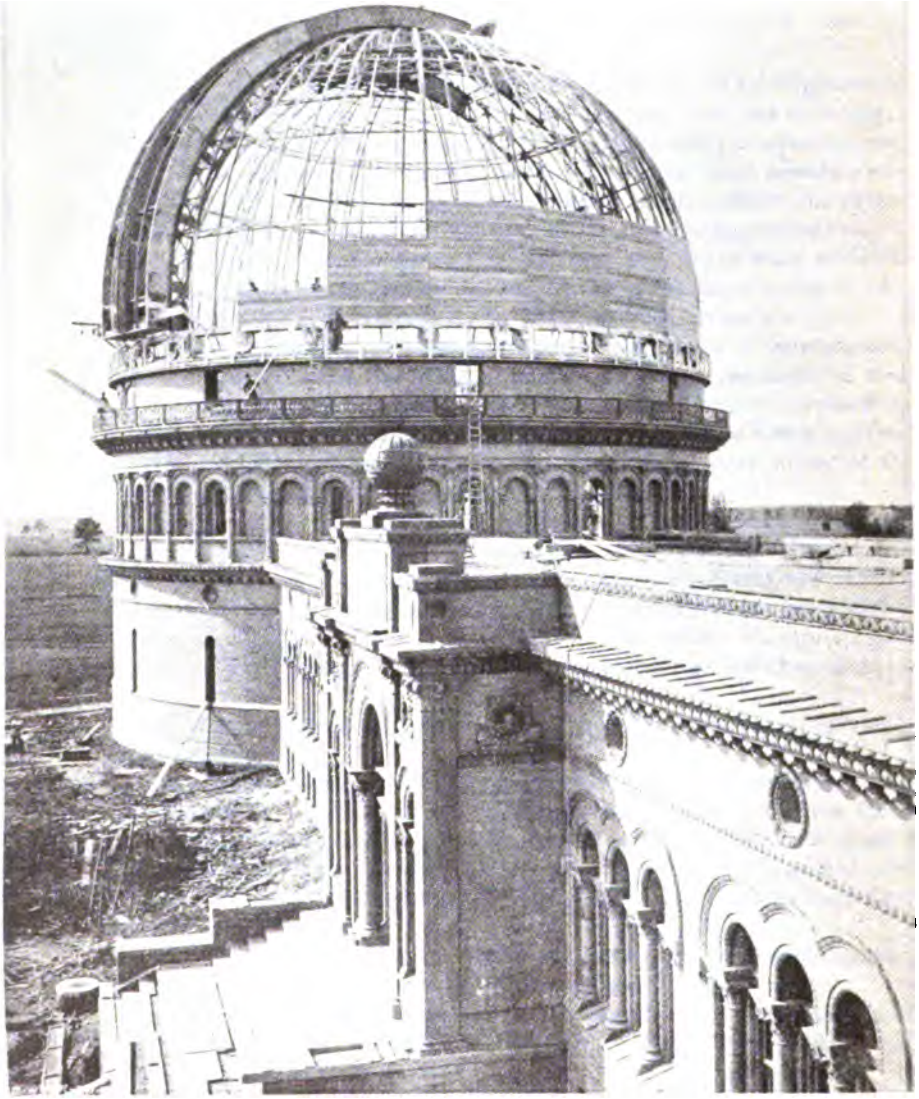
PLATE XIII.



RKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

October 1896.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME IV DECEMBER 1896 NUMBER 5

OXYGEN IN THE SUN.

By C. RUNGE and F. PASCHEN.

IN the spectrum of a vacuum tube filled with oxygen Piazzi Smyth discovered a line of wave-length about 7775.[1] This line we have lately found to consist of three components, of which the strongest is the most refrangible and the weakest the least refrangible. They seem to coincide with three lines of the same relative intensities in the solar spectrum.

Oxygen vacuum tube	Mean error	Higgs' photographic atlas of the normal solar spectrum	REMARKS
7772.26	0.07	7772.20	Strongest line
7774.30	0.15	7774.43	
7775.97		7775.62	Weakest line

We had to use small dispersion for the sake of intensity and measured the middle of the two weaker lines with a wide slit, which did not separate them. Less weight must be given to their distance measured with a narrow slit, for with a narrow slit it was difficult to see them.

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[1] PIAZZI SMYTH, *Trans. R. Soc. Edinburgh*, 32, Part 3, 1883. No condenser or spark-gap must be interposed in the circuit.

The coincidence would not be convincing if there were many lines in this region of the solar spectrum. But as the following drawing shows, in which the solar spectrum is copied from Higgs' photographic atlas, there are very few lines in the neighborhood. Considering at the same time the accordance of the relative intensities there remains little doubt that the coincidences are real. In the more refrangible parts of the solar spectrum the lines are so closely set that the coincidences of the other oxygen lines with solar lines, which have been maintained by several authors, carry far less evidence.

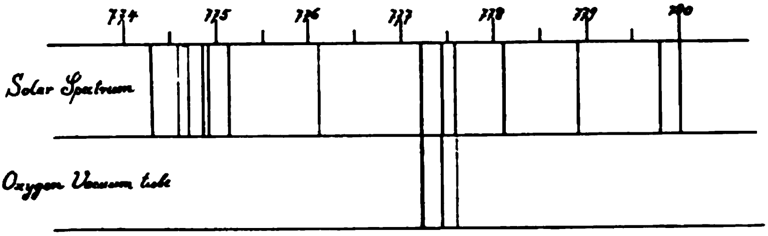


FIG. 1.

In order that the probability of a real coincidence remain the same, the accuracy should be proportional to the density of the lines.

If it could be shown that the three lines are not atmospheric lines, the presence of oxygen in the Sun would be proved. From general principles it may be said that an atmospheric origin seems improbable. For the spectrum of the oxygen vacuum tube differs widely from the absorption spectrum of atmospheric oxygen, as there is no trace of the bands A, B, etc., so prominent in the spectrum of the atmosphere.

The comparison of the spectra of high and low Sun is a better test. Mr. F. McClean has had the kindness to examine the appearance of the three lines on his negatives of the spectra of the high and low Sun. He thinks they do not depend on the elevation of the Sun above the horizon.

But there still remains a doubt. For if the lines originate in the oxygen of the highest layers of the atmosphere, which for ought we know may have a spectrum different from that of the lower layers, high and low Sun might make little difference in the thickness of the layers traversed by the rays. A conclusive test of the true solar origin of the lines can only consist in a determination of their displacement on the Sun's limb. We hope that some one better equipped for this kind of work than we are will undertake to settle the question.

THE ALGOL VARIABLE + 17° 4367. W DELPHINI.

By Edward C. Pickering.

An ephemeris of the times of heliocentric minima of the Algol variable + 17° 4367 will be found in the Astrophysical Journal, 3, 200. The formula employed is *J. D.* 2412002.500 + 4.8064 *E*. A continuation of this ephemeris is given below in Table I. for the year 1897. The form is slightly modified so that the number of the epoch is given in the first column, the Julian Day in the second column, omitting the constant number 2410000, the calendar date in the third column, and the Greenwich Mean Time expressed in hours and minutes in the fourth column. If the tenth of a minute is required it can be obtained from the second column.

TABLE I.

EPHEMERIS FOR 1897.

E.	J. D.	Date	G. M. T.	E.	J. D.	Date	G. M. T.
401	3929.8664	Jan. 4	20h 47m	423	4035.6072	Apr. 20	14h 34m
402	3934.6728	" 9	16 09	424	4040.4136	" 25	9 56
403	3939.4792	" 14	11 30	425	4045.2200	" 30	5 17
404	3944.2856	" 19	6 52	426	4050.0264	May 5	0 38
405	3949.0920	" 24	2 12	427	4054.8328	" 9	20 00
406	3953.8984	" 28	21 33	428	4059.6392	" 14	15 20
407	3958.7048	Feb. 2	16 55	429	4064.4456	" 19	10 42
408	3963.5112	" 7	12 16	430	4069.2520	" 24	6 03
409	3968.3176	" 12	19 38	431	4074.0584	" 29	1 24
410	3973.1240	" 17	2 58	432	4078.8648	June 2	20 45
411	3977.9304	" 21	22 19	433	4083.6712	" 7	16 06
412	3982.7368	" 26	17 41	434	4088.4776	" 12	11 28
413	3987.5432	Mar. 3	13 02	435	4093.2840	" 17	6 49
414	3992.3496	" 8	8 24	436	4098.0904	" 22	2 10
415	3997.1560	" 13	3 44	437	4102.8968	" 26	21 31
416	4001.9624	" 17	23 05	438	4107.7032	July 1	16 53
417	4006.7688	" 22	18 27	439	4112.5096	" 6	12 14
418	4011.5752	" 27	13 48	440	4117.3160	" 11	7 35
419	4016.3816	Apr. 1	9 10	441	4122.1224	" 16	2 56
420	4021.1880	" 6	4 31	442	4126.9288	" 20	22 18
421	4025.9944	" 10	23 52	443	4131.7352	" 25	17 38
422	4030.8008	" 15	19 13	444	4136.5416	" 30	13 00

TABLE I.—*Continued.*

EPHEMERIS FOR 1897.

E.	J. D.	Date	G. M. T.	E.	J. D.	Date	G. M. T.
445	4141.3480	Aug. 4	8h 21m	461	4218.2504	Oct. 20	6h 00m
446	4146.1544	" 9	3 42	462	4223.0568	" 25	1 22
447	4150.9608	" 13	23 04	463	4227.8632	" 29	20 43
448	4155.7672	" 18	18 25	464	4232.6696	Nov. 3	16 05
449	4160.5736	" 23	13 46	465	4237.4760	" 8	11 25
450	4165.3800	" 28	9 07	466	4242.2824	" 13	6 46
451	4170.1864	Sept. 2	4 28	467	4247.0888	" 18	2 08
452	4174.9928	" 6	23 50	468	4251.8952	" 22	21 29
453	4179.7992	" 11	19 10	469	4256.7016	" 27	16 51
454	4184.6056	" 16	14 32	470	4261.5080	Dec. 2	12 12
455	4189.4120	" 21	9 53	471	4266.3144	" 7	7 32
456	4194.2184	" 26	5 14	472	4271.1208	" 12	2 54
457	4199.0248	Oct. 1	0 36	473	4275.9272	" 16	22 15
458	4203.8312	" 5	19 57	474	4280.7336	" 21	17 37
459	4208.6376	" 10	15 19	475	4285.5400	" 26	12 57
460	4213.4440	" 15	10 40	476	4290.3464	" 31	8 18

For convenience of computation, it appears best for another year to use the same formula as in 1896. The observations indicate a slight change in the period so that the minima now occur about fifteen minutes before the times given in the ephemeris. A reduction of the observations already made will serve to determine the nature of these changes. They would be approximately represented by diminishing the assumed period, if it is constant, by about two seconds, and calling it 4.80638 instead of 4.8064. This difference was caused by our want of knowledge of the exact form of the light curve when the previous ephemeris was computed.

A correction for the equation of light may be computed by means of Table II., which gives for each tenth day the correction, expressed in seconds, to be added to the observed time to give the time of heliocentric minimum.

TABLE II.

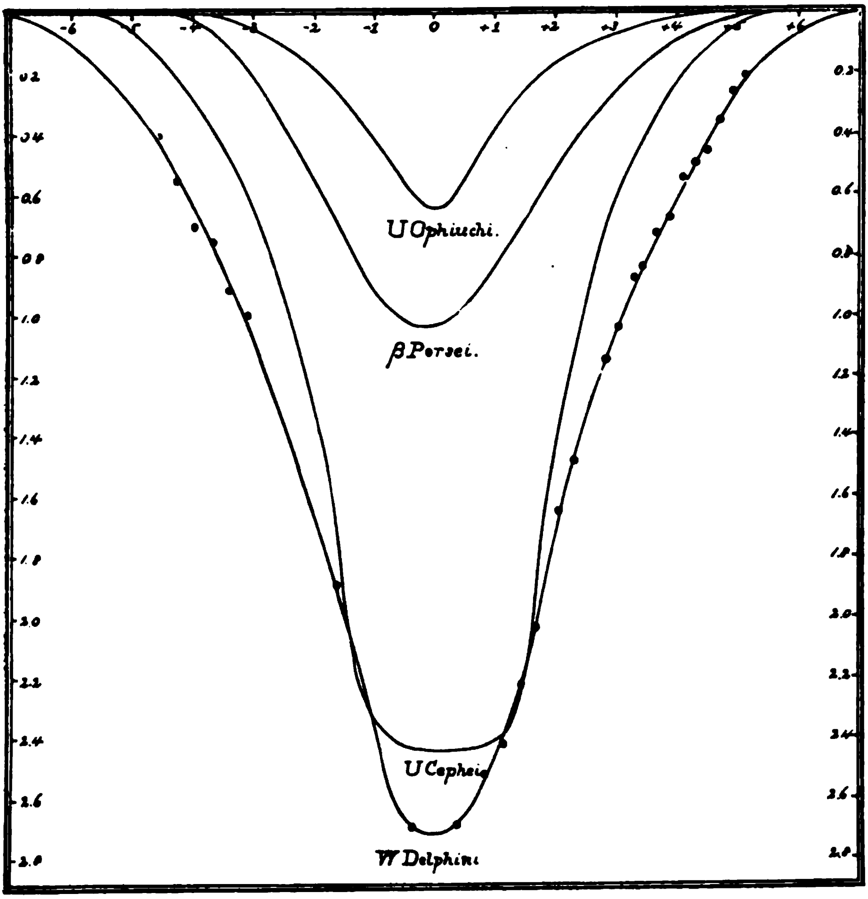
LIGHT EQUATION.

Date	Corr.	Date	Corr.	Date	Corr.
Jan. 0	-319^s	May 10	$+18^s$	Sept. 17	$+325^s$
" 10	−357	" 20	+ 87	" 27	+277
" 20	−383	" 30	+153	Oct. 7	+222
" 30	−398	June 9	+215	" 17	+159
Feb. 9	−401	" 19	+271	" 27	+ 92
" 19	−391	" 29	+319	Nov. 6	+ 22
Mar. 1	−369	July 9	+358	" 16	− 48
" 11	−336	" 19	+387	" 26	−117
" 21	−293	" 29	+405	Dec. 6	−183
" 31	−242	Aug. 8	+412	" 16	−243
Apr. 10	−183	" 18	+407	" 26	−295
" 20	−119	" 28	+391		
" 30	− 51	Sept. 7	+363		

Measures of the variable star were made with the meridian photometer on five nights, and gave the results 9.28, 9.34, 9.27, 9.35 and 9.11. The mean magnitude and average deviationare 9.27 ± 0.06. Similar measures of the adjacent star, $+17^\circ 4368$, gave 9.30 ± 0.05. These two stars have also been compared by Mr. O. C. Wendell with the photometer described in the ASTROPHYSICAL JOURNAL 2, 1889, attached to the 15-inch equatorial. The total number of photometric settings exceeds four thousand. Measures of the full brightness on nine nights indicate that the first star was 0.10 fainter, instead of 0.03 brighter than the second. Combining the results of both photometers, its full brightness has been assumed to be 9.30. These observations also serve to determine the form of light curve whose coördinates are given in Table III.

The form of this light curve is also shown in Plate XIV., in which the earlier observed magnitudes, as determined with the photometer, are represented by dots and the light curve by a smooth line. The average deviation is between one and two-hundredths of a magnitude. The magnitude represented by each dot is in general derived from the mean of eighty photometric settings. The scale is such that five hours on the horizontal scale is represented by the same quantity as one

PLATE XIV.



LIGHT CURVES OF VARIABLE STARS.

magnitude on the vertical scale. Owing to the small number of observations where the star is very faint, there is still some uncertainty regarding the form of this portion of the curve.

TABLE III.

LIGHT CURVE.

Time	Magn.	Time	Magn.
—7^h 00^m	9.30	0^h 00^m	12.01
—6 30	9.34	+0 30	11.93
—6 00	9.42	+1 00	11.73
—5 30	9.50	+1 30	11.42
—5 00	9.60	+2 00	10.96
—4 30	9.77	+2 30	10.60
—4 00	9.96	+3 00	10.32
—3 30	10.17	+3 30	10.08
—3 00	10.41	+4 00	9.88
—2 30	10.70	+4 30	9.70
—2 00	11.01	+5 00	9.55
—1 30	11.34	+5 30	9.44
—1 00	11.69	+6 00	9.36
—0 30	11.97	+6 30	9.31
—0 00	12.01	+7 00	9.30

The light curves of three other variables of the Algol type, U Cephei, β Persei, and U Ophiuchi, have also been determined here photometrically. Their light curves are shown in the plate on the same scale as that of W Delphini. The variation of W Delphini amounts to 2.71 magnitudes, and is greater than that of any other star of this class. U Cephei is second with a variation of 2.44 magnitudes. The variations of β Persei and U Ophiuchi are 1.04 and 0.66 magnitudes respectively. The accuracy with which the form of the light curve can be determined is nearly proportional to the amount of the variation. The star W Delphini is therefore particularly interesting as a test of any theory relating to the dimensions and orbit of the eclipsing body.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Nov. 6, 1896.

THE DETERMINATION OF THE RELATIVE QUANTITIES OF AQUEOUS VAPOR IN THE ATMOSPHERE BY MEANS OF THE ABSORPTION LINES OF THE SPECTRUM.[1]

By L. E. JEWELL.

THE investigation upon which the present report is based was begun by me, in accordance with the recommendation of Professor Henry A. Rowland, January 16, 1892.

In my preliminary report of June 1892, I expressed the belief that much more satisfactory results would be obtained if the investigation of the "rain band," which had then been carried on for about six months, were continued so as to include results for a whole year.

This has been done, and I now have observations from January 16, 1892, to July 31, 1893, inclusive. Those for the latter part of July and during the months of August and September, 1892, were made by Dr. C. P. Cronk and G. N. Wilson of the Baltimore station, U. S. Weather Bureau, to whom I am much indebted.

This report includes the results obtained for the period from January 16, 1892, to January 31, 1893; the observations from the latter date to July 31, 1893, not being as yet reduced.

Observations were made both by eye and by photographic means, but the latter method was soon discontinued as unsuitable for the purpose and dependence placed upon the eye observations alone. A photographic map of that portion of the solar spectrum from wave-lengths 5880 to 5950 was used for selecting a suitable series of solar and water-vapor lines for purposes of comparison (see Plate XV.). For convenience in references the solar lines used for comparison are marked A, B, C, D, etc. (with no reference to the Fraunhofer lines except D_1 and D_2); and the water-vapor lines are marked a, b, c, d, etc. The study

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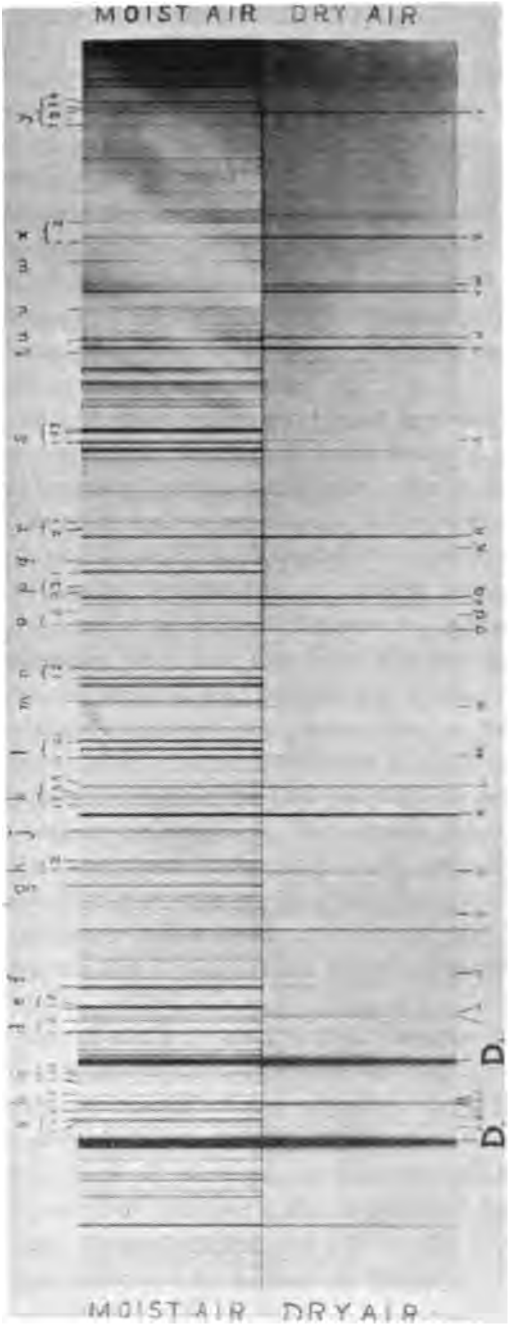
[1] Reprinted by permission from *Bulletin* No. 16 of the Weather Bureau, U. S. Department of Agriculture, with additions and corrections by the author.

PLATE XV.

WATER-VAPOR LINES IN THE SOLAR SPECTRUM.



was confined to this region because there were no entirely suitable photographs at hand of the rest of the rain band, though there are a number of lines in the rest of the band that would be of value in intensity comparisons, as also would be the series of water-vapor lines in the neighborhood of the hydrogen line C.

The method of observation used was to estimate the intensity of a water-vapor line in terms of the solar line most nearly equal to it in intensity, and in close enough proximity to render the comparison easy and sufficiently exact. One observation generally included several comparisons.

A more exact method would have been to make the observation when such a pair of lines (one solar and one water-vapor) were of equal intensity, as the eye is very reliable for such comparisons, but much less so in estimating differences of intensity. This, however, was impracticable under the circumstances, both because of the greater length of time it would require for observations, and because it would make necessary a more extensive series of comparison lines than had been selected in the region of the spectrum to which I had limited the work.

Having selected a series of comparison lines, it became necessary to determine the relative intensities of both the solar and the water-vapor lines used in the comparisons, in order that the observations might be available for actual measurements of intensity and might mean something really definite instead of merely guesswork. For this purpose a photographic scale was constructed, consisting of a series of lines regularly increasing in intensity from a line barely visible to others as strong as were desired.

A large, narrow slit was used, with a gaslight behind it and a plate of ground glass between them, to produce a more even light. A series of images of the slit were then made upon a photographic plate held in a camera, the lens of which had been covered with a piece of wire gauze, fine enough to produce a shading to the edge of the lines and a somewhat diffuse appearance of the lines themselves, but not sufficiently fine to produce any definite side lines due to diffraction fringes.

In the scale thus constructed the exposures were so timed as to be in geometrical ratio, the object being to form a scale of lines whose intensity should vary, as the geometrical series 1, 2, 4, 8, 16, etc. These lines formed the principal divisions, while, to facilitate measurements, an intermediate line was added by making the ratio of the series 1.414 or $\sqrt{2}$.

A fine-grained plate was used and so developed as to secure the best gradation and the clearest background obtainable. In this way a scale was produced, the lines of which closely resembled those in the spectrum of the earth's atmosphere and the better class of lines in the solar spectrum. The scale answered very well for preliminary work, but has several defects, which would be objectionable in more refined work. It is, however, possible to produce a photographic scale which will be entirely satisfactory. It is not true that a series of lines thus produced vary in intensity exactly as a geometrical series, but this is approximately true, and consequently such a scale possesses some of the advantages of a table of logarithms. By its use variations in the spectrum as a whole, such as are caused by the use of different gratings and different orders of spectra, with more or less diffuse light and different widths of slit, can be expressed by a constant, by the application of which observations made with different gratings under different circumstances can be reduced to standard conditions. This was shown experimentally, during the progress of this investigation, by the fact that measurements made in both the first and second order spectra of the grating used differed by a constant, and measurements of the different lines of the oxygen bands differed by constants, irrespective of the elevation of the Sun and the order of spectra or width of slit used. As a consequence of the properties of such a scale all necessary computations and reductions can be greatly simplified and shortened. The observations included in the scope of this paper have only been partly thus reduced, though had the method been extended much labor and time might have been saved.

In measuring the intensities of the solar lines the scale was held in one hand and an eyepiece in the other, and the lines of the scale brought into focus with the solar line to be measured, the latter being brought into position between the two lines of the scale most nearly of the same intensity as the line to be measured. Holding the scale in the hand is not an ideal way of measuring and is not to be recommended, but it answered the purpose of a preliminary set of measurements, and there was no other convenient arrangement available. The relative intensities of the water-vapor lines should have been measured in this way, making several determinations with different degrees of humidity of the air, but this was not done, partly because of the lack of time required for making such measurements and partly because, under the conditions prevailing in Baltimore when the measurements were made, the conditions, otherwise favorable, occurred when the Sun was nearing the horizon and the intensities of the lines were changing too rapidly. Under these circumstances a much less desirable plan was adopted, viz., that of selecting those observations which included a comparison of both the lines to be measured and of the line taken as a standard (l_s) with solar lines, plotting the values thus obtained and deriving in this manner the relative values of the various water-vapor lines selected in terms of the one taken as standard. This plan is not to be recommended, but was the only one that seemed to be available.

In the same way the relation of eye-estimates of differences in intensity to scale values was determined by thus selecting observations which were considered most suitable for the purpose. The results were plotted and a curve drawn representing the relation of eye-estimates to scale values, and by which the differences in intensity as estimated by the eye were reduced to scale values, when the lines compared were not of equal intensity. This determination was not altogether satisfactory, but answered fairly well, as lines were generally selected for comparison which differed but little in intensity.

In Table II. are given the intensities of the solar lines used in terms of the standard line selected (Q) with their approximate wave-lengths.

In Table III. are given the water-vapor lines used, with their intensities in terms of the line selected as standard (l_2) and their approximate wave-lengths.

These values are not so accurate as might be desired, and are known to contain some errors, but on the whole they are fairly well determined, and I do not think it would be worth while to to make a redetermination by the same method.

Considerable trouble was occasioned by a few of the lines being partly solar and partly water-vapor, necessitating special observations to determine how much of the total intensity was due to each source.

Unfortunately, one of the most useful lines, and the one most used for low Sun observations, was found to be of this character. It is a double solar line at wave-length 5914.384, and has a water-vapor component coincident with the red component of the double.

Having finished the determination of the relative intensities of the lines selected and completed a series of observations, the results were put in tabular form and the reductions made as follows: The table (I,) begins with the date of the observation in the first column; then follows what may be called the astronomical data, viz., the time (T) according to eastern standard time; the hour angle (t), plus values representing values west of the meridian and minus values those to the east; the amplitude (A), reckoned from the south point, the signs being the same as for the hour angles; the apparent zenith distance (z), the correction for refraction having been made.

Then follows the amount (α) of atmosphere passed through by the sunlight at the given angle, and in the next column is given the factor (β) for reducing the intensities of the water-vapor lines as observed to what they would be were the Sun in the zenith. This factor is only approximate and varies according to the season, but only the mean value for each month is used.

Then follow the original observations upon the various water-vapor lines, given in terms of the solar line with which they were compared.

TABLE I.—*Original observations and reductions.*

(Extract from the complete table.)

Date	Time	Hour angle	Azimuth	Zenith distance	Amount of air traversed	Factor
1893	*T*	*t* *h* *m*	*A* ° ′	*z* ° ′	*a*	*β*
Jan. 31	8.00 a. m.	....	....	....	....	....
	9.45 a. m.	−2 35	−40 40	67 20	2.58	0.438
	12.30 p. m.	+0 10	+ 2 40	57 00	1.81	0.566
	3.00 p. m.	+2 40	+41 30	67 55	2.64	0.430
	4.57 p. m.	+4 37	+63 30	85 50	11.80	0.144
	8.00 p. m.	....	....	....	....	....

Spectroscopic observations and results.

Intensities as originally observed				Intensities in terms of standard solar line (Q).				Intensities of standard water-vapor line (l).				Resulting intensities (l).	
l_2	n_1	o_1	p_1	l_2	n_1	o_1	p_1	l_2	n_1	o_1	p_1	Mean *m*	Reduced mean *βm*
.....	...	..	....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.1*L*	...	..	0.9*O*	0.573	....	.....	0.460	0.573	.....	.....	0.575	0.574	0.251
0.8*P*	2*N*	..	....	0.355	0.385	.....	.....	0.355	0.503	.....	.....	0.370	0.209
0.8*L*	...	..	0.8*O*	0.500	......	.....	0.438	0.500	.....	.....	0.550	0.525	0.226
0.8*K*	...	*R*	....	(0.907)	......	0.781	.....	1.650	.....	1.320	.....	1.450	0.209
.....	...	..	....	....	.....	.....	.....	.....	.....	.....	...	.....	.....

Meteorological conditions.

Absolute humidity	Dew-point	Relative humidity	Temperature	Pressure	Rainfall
G. p. c. f.	° *F.*	%	° *F.*	*Inches*	*Inches*
1.745	27	70	35.6	30.245	Trace
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	....
1.892	29	75	35.0	30.325	0.00

The next series of columns give these values so reduced as to represent the intensity of the lines observed in terms of the standard solar line (Q).

In the next series of columns are the respective resulting values of the intensity of the standard water-vapor line (I_2) in terms of the standard solar line (Q).

Next is the column of means and then the reduced means giving the means multiplied by the reduction factor (β). This represents the value of the means reduced to what they would be were the Sun in the zenith.

Then follow the meteorological data, viz., the absolute humidity (h) or the amount of water-vapor contained in the air at the Baltimore station, given in grains per cubic foot; the dew point (*D. P.*); the relative humidity (*R. H.*); the temperature of the air (t); the height of the barometer (b), corrected and reduced to sea level; the precipitation (p) for the preceding twelve hours.

For comparison with meteorological data, the midday observation is much the most valuable, as the reduction to standard conditions (the conditions that would prevail were the Sun in the zenith) is less liable to error. Consequently pains were taken to secure as complete a set of midday observations as possible. In addition to these a set of observations at various altitudes of the Sun from noon to sunset were made every few days, in order that satisfactory curves for reducing observations to standard conditions might be constructed.

Considerable attention was also given to observations made upon the approach of both general and local storms and during the approach and prevalence of "cold waves." Observations were not confined to the water-vapor lines, but were occasionally made upon the various lines of oxygen, as it was desired to find the curve representing similar series of observations for one of the least changeable gases of the atmosphere. For this purpose oxygen lines were observed in the same manner as were the water-vapor lines, and, in addition, they were measured frequently by the scale, and the two methods were found to give the same results.

The observations were reduced and plotted and curves drawn representing approximately the mean monthly results. These monthly curves were used to reduce the observations to standard conditions. The daily curves differed considerably during the month, especially during spring and fall, but it was considered best for this investigation to only use a monthly mean curve.

In Table IV., the intensity of the standard water-vapor line at various altitudes of the Sun, during the different months of the year, is given as taken from the mean monthly curves referred to. In addition are given the intensities representing specially interesting conditions, viz., the readings from the curve of January 10, 1893, representing the curve for a "cold wave," and also the mean of the curves for July 14, 15, 16, 17, and 18, 1893, during the prevalence of warm, humid, weather conditions. In the same table are also given the results for oxygen. As this varies scarcely any during the year, a single curve suffices to represent it. The intensities given under oxygen are those of the first line in the tail of a (*i. e.*, the oxygen band a), in terms of the same standard solar line (Q) used for comparison with the water-vapor line.

A study of the values of the intensity curves, as given in Table IV., brings out some interesting results. Not only are the intensities for the summer months much greater than for the winter months, but the forms of the curves, or their slopes, are quite different and also decidedly different from the form of the curve representing oxygen, showing that the character of the distribution of water-vapor in our atmosphere is greatly different from that of oxygen and also greatly different at different seasons.

An interesting fact is the similarity in the curves for December, January, February, and March; the rapid change in the curves during April and the beginning of May; the gradual changes after August and during the fall months. The most remarkable difference, however, is between the conditions prevailing during cold waves and very warm, humid weather. The distribution of water-vapor during cold waves seems to be much like that of oxygen, while during warm, humid weather it is almost entirely different.

In Table IV., the values given in parentheses are somewhat uncertain, observations not having been made at these altitudes; the horizon as seen from the heliostat of the spectroscope is clear only during part of the spring and winter, and the highest altitude of the Sun is at a considerable distance from the zenith during the winter.

As to the usefulness of the spectroscope in meteorological observations, my opinion is that for the study of the distribution of water-vapor in the atmosphere it is of great value, but as an instrument for regular observations upon which are to be based the predictions of future weather conditions, it is not much of an addition to the instruments already in use. It might be of considerable use at times, but hardly sufficient to justify its use at most meteorological stations. However, if a few selected stations were equipped with a simple form of instrument of sufficient dispersive power valuable data might be secured.

The increase in intensity of the water-vapor lines is quite decided upon the approach of a general storm, and depends to some extent upon the direction and the azimuth of the Sun, or the direction in which the instrument is pointed in relation to the position of the storm. There is much less of a change at the approach of a local storm, and if it be a small unimportant one, the strength of the water-vapor lines may scarcely be affected at all. Neither is there any perceptible increase in the intensity of these lines when the Sun is shining through clouds, or when the sunlight passes immediately underneath even a fairly large cumulus cloud. However, there is likely to be a marked diminution in the intensity of the water-vapor lines immediately after, even a small local storm, with an increase again to what it was before if the storm has been an unimportant one.

It may also be of interest to note the fact that there is a difference in the curves representing morning and afternoon observations, especially during the colder part of the year, the slopes of the morning curve being steeper, and showing relatively less water-vapor in the lower region of the air than during the afternoon. In my opinion observations made with small spectroscopes having insufficient dispersion to easily see the various lines distinctly, are worse than useless, as the region of the rain-band contains many solar lines which cannot be distinguished from water-vapor lines without good definition and considerable dispersion.

The pointing of a spectroscope toward the sky, instead of the Sun, will also give erroneous results of scarcely any use whatever for purposes of study.

TABLE II. SOLAR LINES.

Name of line	Intensity $Q=1$	Wave-length	Name of line	Intensity $Q=1$	Wave-length
D_2	4.250	5890.186	L	0.551	5916.475
A*	*	5891.398	M	0.211	5918.773
B	0.072	5892.108	N	0.288	5922.334
C	0.183	5892.920	O	0.483	5928.013
D	0.755	5893.097	P	0.391	5929.898
E	0.060	5893.455	Q	1.000	5930.406
D_1	3.145	5896.154	R^1	0.137	5934.024
F	0.320	5899.518	R	0.781	5934.883
G	0.146	5899.752	S	0.195	5941.985
H	0.197	5902.694	T	0.935	5948.765
I	0.611	5905.895	U	0.355	5949.566
I^1	0.219	5907.060	V	0.680	5952.943
J	0.355	5910.197	W	0.319	5953.386
K*	*	5914.383	X	0.571	5956.923

$$A = 0.215\,Q + 0.135\,l_2$$
$$K = 1.280\,Q + 0.375\,l_2$$

* Intensities of solar lines having atmospheric components.

TABLE III. WATER-VAPOR LINES.

Name of line	Intensity $l_2 = 1$	Wave-length	Name of line	Intensity $l_2 = 1$	Wave-length
a_1	0.235	5891.720	k_4	0.205	5916.800
a_2	0.700	5891.878	l_1	0.425	5918.635
a_3*	*	5892.608	l_2	1.000	5919.860
b_1	0.300	5893.268	l_3	0.413	5920.776
b_2	0.355	5893.725	m	0.500	5922.735
c_1	0.250	5894.605	n_1	0.769	5924.490
c_2	0.270	5895.162	n_2	0.535	5925.220
c_3	0.200	5895.360	o_1	0.590	5928.510
d_1*	*	5898.378	o_2	0.132	5929.350
d_2	0.470	5899.215	o_3	0.085	5929.630
e_{1+2}	0.980		p_3	0.117	5930.815
e_1	0.410	5900.135	p_2	0.125	5931.230
e_2	0.620	5900.260	p_1	0.800	5932.306
f_1*	*	5901.682	q	0.400	5932.998
f_2	0.300	5902.363	r_2	0.135	5935.400
g	0.570	5909.213	r_1	0.295	5936.038
h_1	0.355	5910.398	s_1	0.550	5941.845
h_2	0.500	5910.987	s_2		5942.635
j	0.485	5913.212	s_3		5942.789
k_1	0.250	5915.146	t		5942.452
k_2	0.280	5915.650	u	0.635	5949.390
k_3	0.220	5915.840			

$$a_3 = 0.070\,Q + 0.410\,l_2$$
$$d_1 = 0.030\,Q + 0.840\,l_2$$
$$f_1 = 0.050\,Q + 0.950\,l_2$$

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* Intensities of water-vapor lines having solar components.

TABLE IV.

MEAN INTENSITIES FROM CURVES REPRESENTING THE MEAN VALUES OF βm FOR THE RESPECTIVE MONTHS.

1892.

Zenith distance of Sun		January	February	March	April	May	June
	0°	(0.150)	(0.200)	(0.210)	(0.300)	0.460	0.650
	30	(0.200)	(0.250)	0.275	0.370	0.570	0.860
	50	0.250	0.320	0.325	0.490	0.800	1.300
	70	0.420	0.510	0.500	0.800	1.530	2.430
	80	0.770	0.830	0.790	1.330	2.450	3.650
	85	1.130	1.270	1.170	1.950	3.330	(4.650)
	87 30′	1.490	1.780	1.560	2.530	(4.050)	(5.250)
	89	(1.930)	2.500	2.080	(3.050)	(4.800)	(5.700)
	90	(2.550)	(3.400)	(2.900)	(3.600)	(5.900)	(6.200)
Amount of water (thickness of equivalent layer in inches) held in suspension in the form of water-vapor,		0.670	0.900	0.950	1.370	2.120	3.050

Zenith distance of Sun		July	August	September	October	November	December
	0°	0.560	0.500	(0.320)	(0.340)	(0.260)	(0.180)
	30	0.730	0.670	0.420	(0.440)	(0.340)	(0.230)
	50	1.080	0.950	0.670	0.550	0.440	0.300
	70	2.000	1.600	1.470	1.000	0.770	0.580
	80	3.130	(2.500)	2.380	1.740	1.440	1.080
	85	(4.320)	......	3.250	2.580	2.160	1.620
	87 30′	(5.200)	......	(4.000)	3.500	2.870	2.100
	89	(6.000)	.....	......	(4.300)	3.550	2.700
	90	(6.500)	......	......	(5.200)	(4.500)	(3.700)
Amount of water		2.600	2.310	1.460	1.560	1.180	0.810

TABLE IV.—*Continued.*

1893.

Zenith distance of Sun		January	February	March	April	May	June	July
	0°	(0.160)	(0.180)	(0.230)	0.320	0.400	0.600	0.580
	30	(0.205)	(0.240)	0.300	0.390	0.490	0.760	0.705
	50	0.260	0.310	0.350	0.500	0.640	1.140	0.970
	70	0.410	0.440	0.530	0.960	1.180	1.920	1.770
	80	0.730	0.700	0.920	1.480	2.030	2.700	2.490
	85	1.120	1.070	1.350	(2.000)	2.950	(3.400)	3.010
	87 30′	1.550	1.450	1.720	(2.470)	(3.600)	......	(3.600)
	89	2.060	1.860	2.030	......	......	......	......
	90	(2.750)	2.600	2.700	......	......	......	......
Amount of water	......	0.710	0.810	1.040	1.460	1.850	2.790	2.700

INTENSITIES FROM CURVES REPRESENTING SPECIAL CASES.

Zenith distance of Sun		Cold-wave, January 10, 1893	Warm-wave, July 15, 16, 17, and 18, 1893		Oxygen (1st line in tail of *a*, wave-length = 6287.953)
	0°	(0.080)	1.000		0.240
	30	(0.110)	1.270		0.270
	50	0.140	1.670		0.330
	70	0.201	2.750		0.430
	80	0.310	3.600		0.610
	85	0.485	(4.600)		0.900
	87 30′	0.680	......		1.200
	89	0.930	......		1.550
	90	(1.300)	......		2.000
Amount of water	....	0.355	4.830		......

At the request of Dr. J. S. Ames, the following notes have been added to the above paper on "The Determination of the Relative Quantities of Aqueous Vapor in the Atmosphere, by means of the Absorption Lines of the Spectrum," reprinted from Bulletin No. 16, of the Weather Bureau, Department of Agriculture.

In the original paper it was thought best to confine all remarks to the results obtained. In the following notes a brief statement will be given of the results which in my judgment the spectroscopic method is capable of giving if investigations are carried out along certain lines to which attention will be called.

The basis of all future observational work having for its object the spectroscopic solution of any meteorological problems must be an intensity scale, by means of which the relative intensities of atmospheric lines can be determined with a reasonable degree of accuracy. In the paper referred to is described the photographic scale used in that investigation. As stated there, it was only a provisional scale containing several defects. One can be made, however, which will perfectly answer the purpose, and it is expected that this will be done shortly.

The lines of such a scale should resemble as closely as possible the lines in the spectrum of the Earth's atmosphere, of which the lines in the absorption spectrum of oxygen are the best by which to gauge such a scale.

Without going into the subject exhaustively it may be said that the increase in darkness, or intensity of absorption, from the edge to center of the lines of the scale should be as nearly as possible the same as that of the lines in the absorption spectrum of oxygen. The lines composed should also be of the same width as the oxygen lines in the particular spectroscope used.

A curve representing this change in intensity from margin to center may be called the intensity curve of the line, and can best be reproduced thus: make an aperture of the form of this curve and place an evenly illuminated source of light behind it, draw a small image of this aperture into a line (by using a cylindrical lens) and photograph it. Thus a photographic line can be made which shall resemble as closely as we please the atmospheric lines of the spectrum.

Now as the Sun decreases in altitude and its light passes through increasing thicknesses of absorbing gases in our air, the atmospheric lines increase in both intensity (or darkness) and breadth.

The whole breadth of a line may be considered to be made up of an infinite number of elements, whose varying intensity of absorption gives the line its peculiar character or intensity curve. The central elements have the greatest and the marginal the weakest power of absorption and as the light passes through increasing quantities of the air, the intensity of absorption of each element will increase according to a perfectly definite law of absorption. The change in intensity of the entire line will depend upon the change of the intensity of absorption of each element from the margin to the center as well as the actual value of the absorption of each element for a given amount of the absorbing media.

With the lines of the photographic scale the same thing holds true. If the intensity curve be the same, and for a certain amount of silver deposited the photographed line matches the atmospheric line both in intensity, width, and appearance when both are brought into focus together, then if the amount of silver deposited in the scale line and the amount of absorbing media the sunlight passes through be increased or diminished in the same ratio, the two lines will still match or remain of the same intensity and appearance.

If the silver deposited varied directly as the exposure, then the photographic scale would be a quantitative scale for measuring atmospheric lines, as the intensities would vary precisely alike in the two cases.

The deposit of silver varies nearly as the exposure within certain limits, but gradually changes as the exposure is increased. Such being the case, the scale made by increasing the exposure according to a definite ratio will not form an exact quantitative scale; but fortunately it can be calibrated either by measuring the increase of scale intensity by a very delicate photometer or a bolometer; but a much better plan in practice is to calibrate it by direct comparisons in the spectroscope with the lines of atmospheric oxygen.

This operation can be performed by any good observer with a spectroscope of sufficient power, wherever he may be. The first line in the tail of the α group ($\lambda = 6287.953$) should be taken as the standard, when the Sun is in the zenith, the observer at sea level and the barometer standing at 760^{mm} Comparisons can be made with this standard line at various altitudes of the Sun, and the amount of oxygen passed through by the sunlight can be found by the tables of Forbes and Bouguer, and thus the quantitative values of the scale be determined, or it can be compared with other oxygen lines whose relative intensities have been determined.

A scale such as has been described will fit accurately only that spectrum and grating for which it was made and calibrated, but if the exposures used in making the lines of the scale varied according to geometrical ratio, then the differences of measures made in this particular spectrum and any other will be constant, and as this constant can be applied to measurements they can be readily reduced to standard conditions.

Probably because of conditions as regards temperature prevailing in the solar atmosphere, the true solar lines in the spectrum are not as dark as the lines produced by the gases in the Earth's atmosphere; but by the use of a little judgment the relative intensities of solar lines can be measured quite satisfactorily so that they can be used as standards of reference. The intensities given in Tables II. and III. were made with a scale in some ways defective, and it is important that the lines should be carefully remeasured, particularly those of Table III., which are most in error. It is hoped that this can be done before long.

Numerous observations made upon the various lines of the oxygen bands δ, α, B, and A, have shown that the intensity curve of all of these lines is either exactly the same or very nearly so, unless the line is a double or mixed in some way with other lines. It is so nearly true, that the curves representing the intensities of the lines in the various oxygen bands for various altitudes of the Sun can be reduced to each other by the application of a reducing factor, although the actual intensities of the different lines vary enormously.

Also if two well-determined points be taken upon the curve and the value of the absorption factor be thus determined, a complete curve can be formed theoretically which will fit into the curve representing actual observations within the limits of the errors of observation.

The above facts would indicate that within the limits of variation of pressure to which the oxygen of the atmosphere is subjected, there is no appreciable change in the form of what has been called the intensity curve of absorption lines. It is known, however, that when the pressure is greatly increased beyond one atmosphere the form of this curve is considerably changed, being considerably flattened as the lines are broadened by increasing pressure.

I have dwelt at length upon the case of oxygen because it has an important bearing upon that of water-vapor.

The law governing the distribution of oxygen in the air is quite well known and thė variations to which it is subjected are comparatively slight, and hardly great enough to perceptibly influence the appearance of lines in the absorption spectrum of oxygen, or at least any change will be very small. As a consequence, spectroscopic observations can be compared with known data and the dependence of the varying intensity of the absorption lines upon the variation of the amount of oxygen passed through by the sunlight, determined directly and accurately.

The case of water-vapor is essentially different. The amount of it present in the air is extremely variable with changes in the season and considerably so from day to day. It must also vary greatly for different latitudes and even for different places having the same latitude.

Moreover, the distribution of water-vapor in the atmosphere is practically unknown. Of course some work along this line has been done at mountain observatories and by the aid of baloons and kites, but the results are meager and unsatisfactory. Furthermore, the conditions prevailing at mountain observatories are probably far from being the same as at the same elevation in the air away from the influence of the mountain.

The question that forces itself upon one is: Cannot this problem be attacked spectroscopically? Most assuredly it can, but there are difficulties in the way.

Much time and work has been spent upon this problem but the solution has not yet been obtained because of the lack of necessary and vital data. I have attempted to supply the missing data indirectly but the result is uncertain and therefore unsatisfactory.

Before the problem can be solved, it will be necessary to first construct a more satisfactory photographic scale than the one heretofore used for measurements, and then to determine the intensity of several water-vapor lines after passing through known quantities of water-vapor.

The only satisfactory and the easiest method of securing this data will be to compare the intensities of water-vapor lines when the Sun is nearly overhead and the spectrum obtained directly, with the intensity of the same lines when the sunlight has been caused to pass through a few miles of water-vapor near the Earth's surface. This can be done by placing at a station, a few miles distant, mirrors and a lens so mounted that a strong beam of sunlight can be sent from the station to the heliostat mirror of the spectroscope. The distant station selected should have nearly the same altitude as the observing station, and preferably the country between should be comparatively level and the height of both stations above the surrounding country small.

Observations should be made upon several days having a considerable range of humidity, but unsettled weather should be avoided if possible. Hygrometric observations should be made at both stations, and if convenient at one or more intermediate places, during the progress of the work. In making the spectroscopic observations the width of the slit should remain unchanged and the direct sunlight weakened so as to correspond with the reflected light. Observations should be made by comparing the water-vapor lines with solar lines of the same intensity but the main dependence should be placed upon the scale measurements, and as a check it will be well to measure both some solar and oxygen lines.

Having secured satisfactory measurements made upon days having as wide a range of humidity as necessary for the purpose, we can determine the change in the intensity of water-vapor lines produced by known amounts of water-vapor, and consequently the amount required to produce any given intensity of a line. This will give the quantitative values of the different intensities of the lines in the absorption spectrum of water-vapor; and what has been termed the intensity curve of the lines may be determined. Incidently the photographic scale may be standardized for water-vapor as for oxygen.

Probably all of the single lines of water-vapor will have the same intensity curve, but whether this is so or not can be determined by the use of a good scale. Observations under various conditions for two years indicate that it is true, but it should be tested more carefully with a more satisfactory scale than I used. The intensity curve will be very much like that for the oxygen lines but my investigations, so far, indicate that there is certainly a difference, the slope of the curve being rather steeper. The question as to there being any possible changes in the form of this curve due to considerable differences in density of the water-vapor in our atmosphere is somewhat difficult to answer. It can be investigated, but the investigation is somewhat difficult.

Probably if a set of measurements such as has been referred to be made with quite a large range in the hygrometric conditions the effect of density can be determined, if there is any appreciable effect in the limited range of pressures we are likely to meet in the air. The problem can also be studied by indirect methods but not so satisfactorily. The correct way, however, would be to have two reflecting stations, one of which is considerably farther away than the other, and make a set of observations with light reflected from both; but probably one station with observations made under a sufficiently wide range of hygrometric conditions will give entirely satisfactory data.

The results obtained from oxygen, however, would indicate that at the vapor pressures which we are likely to meet with in the air there would be little if any perceptible change in the form of the intensity curve, though probably great changes would occur if the pressure were increased greatly beyond atmospheric pressure.

Having obtained the data referred to we would be in a position to determine, approximately at least, by making a series of observations during the day from noon to sunset, together with a set made in the morning, not only the total amount of water-vapor held in suspension in the air during the day but also the distribution of the water-vapor at different heights above the Earth's surface, or the hygrometric gradient for altitude.

This cannot be determined directly but must be solved indirectly. Several of the most probable values of the hygrometric gradient for altitude can be used and theoretical curves constructed which would represent the intensities of water-vapor lines for different altitudes of the Sun, based upon these values. These theoretical curves can then be compared with the curves representing actual observations, and in this manner a series of typical curves can be constructed theoretically, which will fit the various curves representing spectroscopic observations; and when this is carefully done, both the hygrometric gradient and the actual amount of water vapor at any given height in the air can be determined. Of course the results will not be as accurate as thermometrical or barometrical observations, but will be approximately correct and give a good idea of the hygrometric conditions prevailing at different altitudes. Local irregularities, however, will be difficult to recognize, the results representing the gradual changes with elevation in which local irregularities are ignored for the most part at least, but this is what we most need in meteorological studies. For this reason, spectroscopic observations are more useful for determining the conditions prevailing at different seasons and studying seasonal changes, than for determining the conditions prevailing during any particular day. They are also very valuable for studying the conditions prevailing with special types of weather, such as cold waves, continued hot, humid, summer weather, or warm waves, and also the approach of extensive storms. The differences in the form of the curves representing these special types are very marked indeed, as is also the difference between the spring and fall months.

It is hardly necessary to say that if the missing data can be supplied and observations made at some of the more important places in different latitudes, results of the greatest value in meteorological study can be obtained; the expense attending such investigations would be exceedingly small when compared with investigations made from baloons or by the aid of kites, and the results obtained would probably be more satisfactory in many ways.

A good grating having large dispersion is absolutely necessary, but an elaborate or expensive mounting is not. Observations made with small instruments, particularly with pocket direct vision spectroscopes are worse than useless, especially if the instrument be pointed to the sky instead of the Sun.

A point of considerable interest in connection with observations made to determine the hygrometric gradient for the air, is that if this be determined satisfactorily and clouds at different heights have been present during the day, and we know fairly well the heights of these clouds, the temperature gradient for altitude can be determined approximately. The amount of moisture being known for a given height at which precipitation is occurring, and consequently the air saturated with moisture, the temperature can be determined approximately. Determinations of this kind, however, being only roughly approximate, are better suited for giving general results or a good idea of the gradient and seasonal changes than for an individual determination for any particular date.

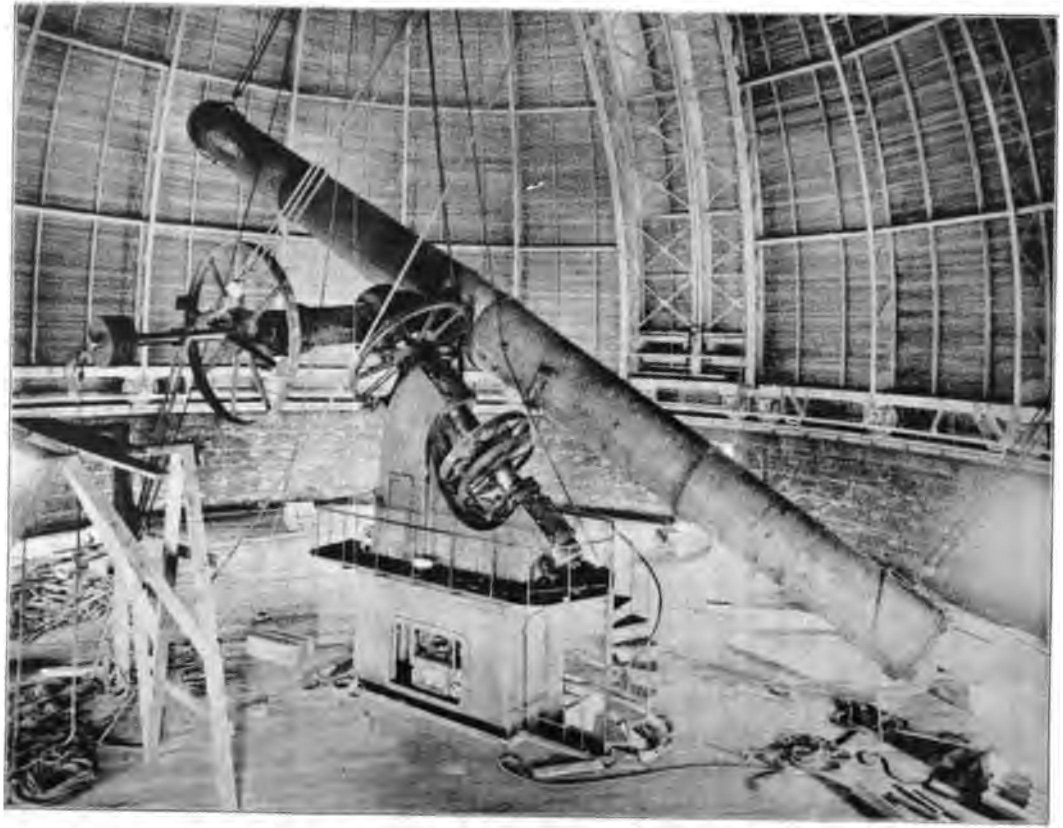
If the missing data can be obtained, the observations made during 1892 and 1893 can be used for determining the total moisture held in suspension in the air throughout the year, and also the hygrometric gradient for altitude; if used together with the observations of clouds made at the Baltimore and Washington stations of the United States Weather Bureau, a rough approximation to the temperature gradient for altitude with the seasonal changes can be obtained.

The approximate values for the total amount of moisture held in suspension during the different months, have been determined by an indirect method and are given at the bottom of Table IV.; but the values are somewhat uncertain and may be either greater or smaller than given. The estimates are probably something like the true values, and the relative values are rather accurate.

Tables II., III., and IV. differ somewhat from the tables as published by the Weather Bureau in being more complete, and Table IV. is here given for nearly nineteen months instead of one year only.

JOHNS HOPKINS UNIVERSITY,
November 1896.

PLATE XVI.



MOUNTING OF THE 40-INCH YERKES TELESCOPE.

NOVEMBER 1896.

The rising-floor is shown at its highest level.

RESEARCHES ON THE ARC-SPECTRA OF THE METALS. III. COBALT AND NICKEL. II.[1]

By B. HASSELBERG.

COBALT AND OTHER METALS PREVIOUSLY INVESTIGATED BY KAYSER AND RUNGE.

IN making these comparisons I have merely used the corresponding tables of wave-lengths, without taking photographs containing the spectra of the two elements in question. The results showed at once that the metals indium, thallium, lead, arsenic, antimony, bismuth, and cadmium have not a single coincidence with cobalt, while potassium, sodium, lithium, cæsium, rubidium, magnesium, tin, and mercury have a few more or less close coincidences, the accidental character of which, however, could not be open to doubt. Similar approximate coincidences between lines of cobalt and of the metals of the alkaline earths are also found, as may be seen in the following table, in which Kayser and Runge's wave-lengths are given, with the uncertainty to which they are subject and other remarks of the authors. These remarks are sufficient to indicate the wholly accidental character of the coincidences.

Co	Ca		
4092.98	92.92	± 0.10	Diff. toward red.
4581.71	81.66	0.10	
4624.70	24.70	0.50	Diff. toward red.

Co	Sr		
3504.81	04.70	± 0.30	Very diffuse.
4607.46	07.52	0.03	Not sharp.
4869.59	69.41	0.10	Diffuse.
4968.09	68.11	0.03	

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[1] Continued from p. 304.

Co	Ba		
3562.22	62.28 ±	0.10	Diffuse.
77.80	77.79	0.05	Diffuse.
3910.08	10.04	0.05	Not sharp.
75.47	75.55	0.10	Diff. toward red.
4179.38	79.57	0.20	Diff. toward red.
5381.30	81.25	0.50	Diff. toward red.

The only line in the above list which, in case of exact coincidence, might possibly be foreign to cobalt, is the line λ 4607.46, since the corresponding strontium line is the very strongest in the spectrum of that metal. But the absence of any trace of the other chief lines of strontium, as well as the still existing uncertainty of the coincidence, seem to justify its retention in the spectrum of cobalt. As for calcium, several of the principal lines occur regularly on my plates; but they are immediately recognizable as foreign lines by the fact that they only appear as fine points at the borders of the spectrum, which is possible only when the vapor producing them is in the immediate vicinity of the electrodes. That these lines belong to calcium is apparent from the following comparison with the corresponding wave-lengths of Kayser and Runge's catalogue.

Co		Ca	
λ	i	λ	i
4226.90	2	26.91	6
83.15	2	83.16	5
89.55	1.2	89.51	5
99.10	1.2	99.14	4
4302.65	2.3	02.68	6
18.86	1.2	18.80	5
4425.60	1.2	25.61	6
35.10	2	35.13	6
35.90	1.2	35.86	5
55.00	2.3	54.97	6

Since electrodes made of electrolytically deposited copper instead of carbon were used in photographing the violet and ultra-violet spectrum, in order to avoid the carbon bands which appear in these regions, there remain to be eliminated only the copper lines which are produced by this method. These lines are fortunately not very numerous, and, with a few easily recognized exceptions, so weak and diffuse that any connection between them and lines of cobalt having nearly the same positions can hardly be assumed. In the following list, obtained by comparison with Kayser and Runge's investigation of the copper spectrum, those lines are shown which have nearly identical positions in the two spectra:

Co		Cu			REMARKS
λ	i	λ		i	
3520.20	3	20.13	± 0.05	3	Diffuse.
3613.90	1.2	13.92	0.05	2	Diffuse.
20.58	2	20.53	0.05	2	Diffuse.
24.47	2	24.41	0.05	2	Diffuse.
41.95	2.3	41.85	0.05	2	Diffuse.
45.36	2	45.38	0.05	2	Diffuse.
52.68	2.3	52.62	0.15	1	Very diffuse.
54.59	2	54.6	0.50	2	Very diffuse.
3734.30	2	34.33	0.05	2	Diffuse.
41.40	1	41.38	0.05	3	Diffuse.
4011.07	1	11.02	0.20	2	Very diffuse.
4275.29	1	75.38	0.05	5	
4531.14	5	31.10	0.10	5	Diffuse.
87.08	1.2	87.25	0.15	6	
4651.28	1.2	51.37	0.10	5	
5105.73	2	05.81	0.05	5	
53.43	1.2	53.29	0.20	5	Very diffuse.
58.61	2	58.59	0.15	1	Diffuse.
5218.42	2	18.52	0.10	6	Diffuse.

This table may be divided into two parts. The second part, beginning with the line λ 4275, was derived from photographs taken with carbon electrodes, while for the first part electrodes of copper were used. Now in the second part there are cobalt lines which nearly coincide with the strongest copper lines, and it might therefore be doubted whether these lines belong to the cobalt spectrum. If they are regarded as actually belonging to copper, then either the electrodes or the cobalt must have contained copper as an impurity. The former assumption is negatived by the fact that no trace of these lines is found on the plates of the nickel spectrum, which were obtained with electrodes of the same manufacture. The nickel itself is also shown to be free from these lines, and the existence of the copper in the cobalt is thereby rendered improbable. At present, therefore, I am disposed to regard the close coincidence as accidental, especially since, on the one hand, the uncertainty of Kayser and Runge's wave-lengths does not allow a final decision as to coincidence or non-coincidence to be made, and, on the other hand, the diffuseness of the copper lines gives them a character entirely different from that of the sharp lines of cobalt. As for the lines in the first part of the table, the probability of coincidence, when the smaller uncertainty of the wave-lengths in the copper spectrum is taken into account, is somewhat greater; but in consideration of the fact that all the copper lines are weak and diffuse, the cobalt lines, on the contrary, strong and sharp, a real connection between them can hardly be assumed. This mode of regarding the question finds support in the circumstance that if it were incorrect, the same lines must appear in the corresponding parts of the spectrum of nickel, as these were also obtained with copper electrodes; this, however, is not the case.

COMPARISON OF THE NICKEL SPECTRUM WITH PREVIOUSLY KNOWN SPECTRA OF OTHER METALS.

NICKEL AND IRON.

Although, as in the case of cobalt, the iron lines on the plates were sifted out as carefully as possible in the first examination of the photographs of the nickel spectrum, a subsequent comparison with Kayser and Runge's catalogue of iron lines yielded a very considerable number of approximate coincidences, which made necessary a more thorough investigation with the aid of plates containing the spectra of both substances. The result is shown in the following table:

Ni		Fe		REMARKS
λ	i	λ	i	
3458.59	4	58.61	2	Coinc. Belong to Ni.
61.78	4	61.79	2	
62.95	1	62.93	1	Fe missing.
72.68	3.4	72.67	1	Fe missing. Belongs to Ni.
74.21	1.2	74.20	1	Fe missing. Belongs to Co, Mn.
76.19	1.2	76.23	1	Fe missing.
78.04	1	77.99	2	Very weak. Coinc.?
83.93	3	83.97	1	Fe missing. Belongs to Cu.
89.59	1	89.55	1	Fe missing. Belongs to Co.
93.10	4.5	93.10	2	Coinc. Belongs to Ni.
3502.44	1.2	02.41	1	Fe missing. Belongs to Co.
06.47	1.2	06.45	1	Fe missing. Belongs to Co.
10.47	4	10.49	1	Trace of Fe. Belongs to Ni.
12.78	1	12.84	1	Fe missing. Belongs to Co.
15.17	4.5	15.21	2	Coinc. Belongs to Ni.
18.80	2	18.86	1	Fe missing.
24.65	5	24.68	2	Coinc. Belongs to Ni.
29.93	1.2	29.96	3	Coinc. Belongs to Co.
30.51	2	30.54	2	Coinc. Belongs to Ti.
53.63	2	53.64	1	Fe missing.
66.50	4.5	66.52	2	Coinc. Belongs to Ni.
75.52	1.2	75.55	3	Coinc. Belongs to Co.
87.32	1.2	87.40	1	Divided. Belongs to Co.
97.84	3.4	97.90	1	Trace of Fe. Coinc.
99.27	2	99.18	1	Coinc. λ Fe = 99.28? Also Co.
3613.90	1.2	13.81	1	Divided.
27.93	1	27.97	1	Fe missing. Belongs to Co.
64.24	3	64.16	1	Divided.
69.38	2	69.35	2	Fe missing.
3739.36	2.3	39.28	1	Divided.
49.15	2	49.12	2	Divided, λ Ni > λ Fe.
3845.58	2.3	45.64	1	Trace of Fe, Coinc. Belongs to Co.
76.96	1.2	76.87	1	Divided. Belongs to Co.
94.20	2.3	94.15	2	Divided. The lines do not belong to Ni and Fe, but to Co and Cr.
3905.67	1.2	05.70	1	Fe missing.
10.07	1.2	10.01	3	Divided, λ Ni > λ Fe.
58.35	1	58.35	1	Missing.
66.20	1	66.22	3	Coinc. Belongs to Fe.
66.78	1	66.76	3	Coinc. Belongs to Fe.
70.65	2	70.57	3	Divided, λ Ni > λ Fe.
74.83	2	74.87	1	Divided, λ Ni < λ Fe.
81.90	1	81.93	4	Probably divided. Int. Ni = 2. Belongs to Ti.
84.18	2	84.14	1	Divided, λ Ni > λ Fe.
89.90	1	90.00	2	Divided, λ Ni < λ Fe. Int. Ni = 2.
95.45	3.4	95.40	1	Divided, λ Ni > λ Fe.
98.77	1.2	98.82	1	Fe missing. Int. Ni > 1.2.
4010.14	1.2	10.11	1	Fe doubtful.
18.24	1	18.27	1	Coinc. Belongs to Mn.
19.20	1.2	19.19	1	Coinc.?
41.52	2	41.59	3	Coinc. Belongs to Mn.
48.87	1	48.88	2	Coinc. Belongs to Mn.
55.68	1.2	55.69	3	Coinc. Belongs to Mn.

Ni		Fe		REMARKS
λ	i	λ	i	
4057.45	1	57.49	3	Divided, λ Ni < λ Fe.
58.36	1	58.36	3	Belongs to Co, Fe.
58.91	1	58.92	3	Coinc. Belongs to Fe, Cr.
59.07	1	59.06	1	Coinc. Belongs to Mn.
64.55	2	64.61	2	Divided, λ Ni < λ Fe.
92.55	2	92.48	3	Belongs to Ni.
4121.48	3	21.54	1	Fe missing.
23.96	1	23.87	3	Divided, λ Ni > λ Fe.
42.34	1	42.37	1	Fe missing.
50.55	1.2	50.48	3	Divided, λ Ni > λ Fe.
95.71	2.3	95.77	2	Divided, λ Ni < λ Fe.
4252.25	1	52.33	1	
4436.52	1	36.51	1	Belongs to Mn.
37.17	2.3	37.10	2	Divided, λ Ni > λ Fe.
42.61	2	42.52	5	Divided, λ Ni > λ Fe.
50.44	1	50.50	2	Missing.
51.72	1.2	51.77	2	Coinc. Belongs to Mn.
4534.21	1	34.19	1	Belongs to Co.
47.15	3	47.20	3	Divided, λ Ni < λ Fe.
65.78	1.2	65.87	2	Divided, λ Ni < λ Fe.
80.77	1.2	80.73	2	Coinc.
81.79	1	81.72	3	Divided. The line under Ni belongs to Co.
96.11	2	96.20	2	Divided.
4606.37	2.3	06.40	1	Fe missing.
4712.24	1	12.27	1	Fe doubtful.
52.58	2	52.56	1	Fe missing.
83.53	1	83.62	3	Divided, λ Ni < λ Fe. The Fe line belongs to Mn.
99.98	1	4800.04	1	Divided, λ Ni < λ Fe.
4832.86	1.2	32.90	2	Divided, λ Ni < λ Fe.
38.80	2	38.72	1	Divided, λ Ni > Fe.
43.27	1	43.37	2	Coinc. λ Fe apparently in error by 0.10.
4937.51	2	37.50	1	Fe missing.
97.04	1	97.06	1	
5012.62	2	12.56	1	
18.50	2	18.59	3	Divided, λ Ni < λ Fe.
51.74	1	51 78	4	Divided, λ Ni < λ Fe.
84.27	4	84.32	1	Fe missing.
97.06	2	97.13	3	Divided, λ Ni < λ Fe.
5100.13	3.4	00.06	1	Fe missing.
21.74	1.2	21.77	2	Divided, λ Ni < λ Fe.
25.39	2.3	25.33	5	Divided, λ Ni > λ Fe.
42.96	3.4	43.05	3	Divided.
46.64	4	46.63	1	Fe missing.
86.80	1	86.71	1	Fe missing.
5218.41	1	18.36	2	Belongs to Co.
5371.64	2.3	71.68	6	Divided, λ Fe > λ Ni.
5504.50	1.2	04.57	1	Fe missing.
5637.32	2	37.35	1	
49.90	2.3	49.96	1	
95.22	3	95.27	1	
5712.10	3	12.08	2	Only a trace of Fe.
15.31	3	15.30	3	Fe extremely faint.
82.34	1	82.34	5	Fe missing.

The same conditions are seen here as in the case of cobalt. We find, namely, that a considerable number (about a third) of the approximate coincidences recorded above consist of pairs of lines, the components of which are distinctly separated, although by only a very small interval, while the iron lines corresponding to the other two-thirds are not found on my plates. The origin of the remaining pairs for which coincidence is assured can in several cases be ascribed with certainty to foreign metals (manganese), and these metals therefore exist as impurities in the nickel used by me, and in the iron used by Kayser and Runge. Setting these lines aside, there remains only a comparatively small number of doubtful cases, the lines being as follows:

λ	i	
	Ni	Fe
3478.04	1	2
3958.35	1	1
4010.14	1.2	1
4019.20	1.2	1
4252.25	1	1
4580.77	1.2	1.2

That the first elimination of the iron lines was a very complete one is apparent in the fact that there are only two lines in the table of which it can safely be asserted that they belong to iron and not to nickel. These are the lines λ 3966.20 and λ 3966.78. On the other hand the line λ 5732.84 is certainly not iron, notwithstanding its great intensity as observed by Kayser and Runge, since it neither appears on my plates nor was it found in iron by Rowland. On account of its feeble intensity in the nickel spectrum I have stricken it from the list of nickel lines, as very probably due to an impurity. As for the line λ 5715.31, which it is perfectly certain occurs also in titanium, a judgment founded on Kayser and Runge's value for the intensity must ascribe it also to iron; but the extreme faintness of the line on my plates causes me to feel doubtful of this.

NICKEL AND TITANIUM.

For a comparison of the spectra of these two metals I may refer to my investigation of the titanium spectrum; with respect to

NICKEL AND MANGANESE

an examination of the plates containing both spectra gives the results exhibited in the following table:

Ni		Mn		Belongs to	REMARKS	
λ	i	λ	i			
3474.21	1.2	74.20	2.3	Co	Intensity variable in Mn.	74.20
3548.34	2.3	48.35	2.3	Ni, Mn	Coincident.	
69.51	1.2	69.51	4		Divided, λ Mn > λ Ni. The line under Ni belongs to Co.	
99.27	2	99.30	1	Ni, Co		
3619.52	5	19.42	3		Divided.	19.60
70.57	2.3	70.67	1.2		Divided.	
3729.05	1	29.05	2		Divided, λ Ni > λ Mn.	
36.94	3.4	37.03	1.2		Divided, λ Mn > λ Ni.	
3823.65	1.2	23.64	4	Mn, Cr		23.72
38.42	3	38.41	3.4	Mg	Coin. Int. Ni variable.	
45.58	2.3	45.58	1.2	Co		45.64
73.25	2.2	73.23	1.2	Co		
74.08	2	74.08	1.2	Co		
94.20	2.3	94.21	1.2	Co		94.15
3953.07	2	53.00	2		Divided, λ Ni > λ Mn.	
84.18	2	84.31	1		Divided, λ Mn > λ Ni.	84.14
87.26	1	87.23	2	Mn		
95.45	3.4	95.45	1	Ni, Co		95.40
4018.24	1	18.25	3.4	Mn		18.27
41.52	2	41.49	5	Mn		41.50
48.87	1	48.88	4	Mn		48.88
55.68	1.2	55.68	4.5	Mn		55.69
58.07	1	58.10	2.3	Mn		
59.07	1	59.08	3.4	Mn		59.05
92.55	2	92.55	1.2	Co		92.49
4131.33	1	31.26	2.3	Mn		
49.00	1	48.95	2.3	Mn		
4201.88	2.3	01.88	2		Divided, λ Mn > λ Ni.	
35.30	1	35.28	3	Mn		
35.46	1	35.45	3	Mn		35.47
84.20	1	84.22	2.3	Mn		84.26
4436.52	1	36.52	3	Mn		36.56
51.73	1.2	51.75	3.4	Mn		51.77
55.48	1	55.50	3	Mn		
4783.53	1	83.60	5	Mn		83.62
4823.67	1	23.71	5	Mn	Coinc.	23.69
5017.75	3.4	17.78	2		Probably divided, λ Mn > λ Ni.	
5197.40	1	97.44	1		Coinc.	
5388.71	1	88.76	1.2		Divided.	
5504.50	1.2	04.53	1.2		Divided, λ Ni < λ Mn.	

It is apparent that in almost all cases in which the lines are not divided or are to be ascribed to cobalt, they belong to manganese. They are for the most part the same lines which were recognized as impurities in photographing the cobalt spectrum. As entirely foreign is to be regarded the line λ 3838.42, which appears with different intensities on various plates of the nickel spectrum, and which certainly therefore does not belong to nickel. If this line has a constant intensity in the manganese spectrum it probably belongs to manganese as well as to magnesium.

NICKEL AND CHROMIUM.

Beside those lines which were found in the investigation of chromium, and which cannot be divided from the nickel lines having nearly identical positions, I have found on repeating the examination the following pairs, the origins of which must for the present remain undecided.

Ni		Cr	
λ	i	λ	i
3683.65	1	83.60	1.2
88.58	2.3	88.56	1.2
3730.88	1.2	30.91	2
3994.13	2	94.10	1.2
4046.91	1	46.89	1
75.05	1.2	75.01	1.2
4284.83	2.3	84.84	1.2
4383.05	1	83.04	1.2
4490.71	2	90.70	1.2

The two lines λ 3688.58 and λ 4284.83 must probably, if the coincidence is exact, be removed from the chromium spectrum; there appears however to be a slight difference of position, at least with respect to the latter line, since the nickel line is very slightly more refrangible than the chromium line.

NICKEL AND OTHER METALS.

In comparing the spectrum of nickel with that of other metals investigated by Kayser and Runge, I have found only the following few cases of coincidences in which the approximation corresponds to the probable error of measurement:

NICKEL		OTHER METALS		
λ	i	λ	i	
3832.44	2.3	32.46 ±0.03	6	Mg
3683.65	1	83.63	5	Pb
5504.50	1.2	04.48 0.05	6	Sr
3577.37	1	77.45 0.10	1	Sr
3610.60	4	10.66 0.03	6	Cd
5709.80	3.4	09.82 0.15	2.3	Ba
5424.85	2	24.82 0.05	5	Ba
4605.15	4	05.11 0.05	2	Ba

The agreement of these positions must, considering the limits of accuracy given by Kayser and Runge for their wave-lengths, be regarded as exact. Nevertheless, the coincidences are quite certainly accidental, partly because no other lines of these metals are found in the nickel spectrum, and partly because the lines have often a totally different character. The lines of nickel are all sharp, while those of the other metals are diffuse, and even unsymmetrically diffuse. We have therefore in the above table an additional illustration of the fact that two different metals may emit rays of so nearly identical periods that they cannot be separately distinguished without a materially greater precision of measurement than that which it has been possible to attain in this investigation.

With the entire remaining series of metallic spectra investigated by Kayser and Runge, the spectrum of nickel either has no connection whatever, or, when an isolated case of coincidence occurs, no doubt can be felt as to its accidental character in view of the reasoning above given, and when the considerable uncertainty of some of Kayser and Runge's measures is taken into account.

After this explanation I give in the following table the wave-lengths of the lines which may be ascribed to these two metals. The arrangement of the catalogue is the same as that previously adopted, and it therefore requires no further explanation. With reference to the last column, however, it may be noted that the earlier measures of Thalén and Liveing and Dewar are there given, reduced to the wave-length system of Rowland.

SPECTRUM OF COBALT.

Cobalt λ	R.	i		Remarks	Liveing and Dewar
		Co	⊙		
3471.52		2.3	3	⊙ double? { 71.47 Fe .52 Co	
74.15		4	3	Diffuse; reversed; ⊙ double? violet component = Co	73.95
74.66		2	1	⊙ double.	
76.49		2	2		76.55
78.01		1.2	1.2		
78.69		2	2	}	78.55
78.90		2	1.2		
80.16		1.2	—		
83.55		3	2	Reversed.	83.25
85.49		3.4	2.3	Also an important Fe line.	85.25
87.86		2	1	Near 87.82 Ca (according to K.-R.).	
89.54		4	2.3	Reversed.	89.36
90.89		2.3	?		
91.46		2.3	2.3		91.16
——	3491.46				
92.15		1.2	1.2		
95.82		3.4	2.3		95.66
96.83		3	2	Reversed. ⊙ double.	96.56
3502.41		4.5	3	Diffuse; reversed.	02.16
02.76		3	2.3	Diffuse; reversed.	02.56
03.86		1.2	1		03.96
04.88		2	?		
05.28		1.2	—		
06.44		4	3	Diffuse reversed.	06 16
09.98		3.4	2	⊙ double; divided from 10.01 Fe	09.86
10.53		3.4	3	⊙ double? Co = red component.	10.26
12.78		3.4	2.3		12.56
13.62		3.4	2.3		
3518.49		3.4	2.3		18.26
——	3518.49				
19.90		2	3	Ni, Co?	
20.20		3	3		20.06
21.70		3	2.3	Reversed.	21.46
23.00		2	2	Divided from 23.03 Fe.	
23.57		3	2	Reversed; ⊙ double { 23.47 .57 Co	23.46
23.85		2.3	1.2		
25.97		1.2	2		
26.96		4.5	2.3	Diffuse; reversed.	26.86
29.17		3	2		28.96
29.92		4.5	3	Diffuse; reversed; also a weak Fe line.	29.87
33.49		3.4	1	Reversed.	33.37
34.92		2	?		
43.40		3	1.2	Very sharp.	43.37
——	3545 33				
46.86		2	1		
48.60		2.3	1		48.57
50.72		3	2	Reversed.	50.67
52.85		2	1	} ⊙ triple { 52.85 Co .98 Fe 53.12 Co	52.97
53.12		2.3	1		

Cobalt λ	R.	i		REMARKS	Liveing and Dewar
		Co	⊙		
3552.28		1.2	1		
58.90		2.3	2	Very sharp.	
60.44		2	—		
61.01		3	2	Reversed.	61.07
62.22		2.3	1	Very sharp.	
63.04		2.3	1	Very sharp.	
64.25		2	2		
65.08		3	2	Reversed.	65.07
68.36		1.2	2		
69.48		5	2	Very diffuse ; reversed.	69.47
——	3570.22				
75.06		3	2	Diffuse ; reversed.	75.07
75.48		3.4	2	Diffuse ; reversed.	75.47
77.36		1.2	1.2	Ni, Co?	
77.80		1.2	?		
78.20		2	1		77.98
79.01		2	?		
79.16		2	?		
82.00		2	?		
84.92		2.3	1.2	Very sharp.	
85.28		3.4	2	Reversed.	85.28
85.92		1.2	?	Divided from 85.90 Fe	
86.20		1.2	?	⊙ double? { 86.20 Co .30 Fe	
87.30		5	3.4	Diffuse ; reversed.	87.28
89.44		1	—		
91.92		1.2	1		
95.00		3.4	2	Reversed.	94.98
96.67		2	1		
——	3597.10				
3600.99		1.2	—		
04.62		2	1		
05.19		2	1		
05.50		3	3	⊙ double? { 05.50 Co .62 Fe	05.58
08.50		1.2	—	Divided from 08.55 Mn	
09.92		1.2	1		
11.89		2.3	1.2		11.88
——	3612.22				
15.56		2	1		15.38
18.17		1.2	?		
20.59		2	2		
24.48		2	2		
25.13		2.3	1		
27.96		3.4	2		27.88
31.55		3	—		
32.12		2	—		
33.00		2.3	1.2		32.78
33.52		1.2	?	Sharp.	
34.86		2.3	2		34.78
36.89		2	2	Very sharp.	36.68
37.49		2	—	Very sharp; divided from 37.45 Fe	

Cobalt λ	R.	i		REMARKS	Liveing and Dewar
		Co	⊙		
3639.63		2.3	1.2	⊙ line probably double.	39.48
——	3640.54				
41.95		2.3	1.2		41.68
43.34		2.3	—	On the edge of the ⊙ line 43.30.	43.28
45.36		2	—		
45.60		1.2	?		
47.25		2	1		
47.82		2.3	?		
48.30		2	?		
49.47		3	2.3	Also an unimportant Fe line.	49.38
51.42		2	—	Very sharp.	
52.68		2.3	2		
54.59		2	1	Very sharp.	54.58
57.12		2	1	Sharp.	56.68
58.05		1.2	2	Also a weak Fe line.	
62.33		—	—	Divided from 62.37 Ti.	62.38
——	3667.40				
70.20		1.2	2		
76.69		3	1.2		
83.18		3.4	2.3	Also Fe.	83.09
84.62		2.3	1		
85.13		1.2	—		
86.63		1.2	—		
90.87		2	2	Very sharp.	90.79
93.27		2.3	—		92.99
93.53		1.2	1		
93.65		2.3	2	Sharp. Divided from 93.70 Mn.	93.39
——	3695.19				
3702.40		2.3	2		02.30
04.17		3	2.3		04.10
07.61		2	1.2	⊙ double { 07.60 Co. 07.70 Ti.	
08.96		2.3	1.2		
11.80		1.2	1		
12.31		2	1		12.20
26.80		1.2	1		
30.61		2.3	2	⊙ close triple { 30.43 Fe. .50 Fe. .60 Co.	33.40[1]
31.42		1	1		
——	3732.54				
32.52		3	2.3	Also Fe.	
33.62		2.3	1.2		33.40
34.30		2.3	1.2	Sharp Cu has 34.33, but the line is diffuse and weak.	
36.05		2.3	1.2		35.80
40.31		2	?		
45.61		3.4	?		46.40
50.06		2.3	1		
51.75		2	1.2		
52.95		1	—		
54.50		1.2	—	Sharp.	

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[1] Sic. 31.40? Eds.

Cobalt λ	R.	i		**Remarks**	Liveing and Dewar
		Co	⊙		
3755.59		2.3	1	Sharp.	54.50
——	3756.21				
59.83		1.2	—		
60.52		1.2	—		
74.72		2	?	Divided from 74.75 (Mn ?)	74.60
77.65		2	—		77.60
——	3783.67				
3805.90		1.2	1		
08.24		2	1.2		07.91
11.16		1.2	1.2		
12.57		1.2	1		
14.58		2	—		
16.46		2.3	2		15.72
16 58		2.3	1		16.31
17.02		2	?	Does not coincide with ⊙ 17.05.	
18.08		1.2	?		
20.02		2	?		
33.02		1.2	1.2		
35.82		1.2	?		
36.04		1.2	—		
41.60		2	1	Sharp.	
42.20		3.4	2	Diffuse.	42.02
——	3843.41				
43.90		2	2		
45.59		4.5	2.3	Diffuse. Reversed.	45.42
50.24		1.2	?		
51.09		2.3	—	Very diffuse. Perhaps a weak ⊙ line, close to the strong line 51.00 (Fe).	
51.97		2	1		
56.93		2	—	Very sharp.	
60.55		2	1	Also Mn.	
• 61.29		3	?		61.12
63.72		1.2	2		
66.92		1	1.2		
70.65		2	1.2	Sharp.	
73.25		4.5	2.3	Diffuse. Reversed.	73.02
74.10		3.4	2.3	Diffuse.	73.82
——	3875.22				
76.99		3	2		76.72
80.54		1.2	2		
81.18		1.2	2		
82.04		3.4	2.3	⊙ probably double $\begin{cases} 82.04 \text{ Co.} \\ .12. \end{cases}$	81.63
84.76		2.3	2	Very sharp.	84.63
85.40		2	2.3	Very sharp. ⊙ perhaps double. Co represents violet component. Red component stronger, = Fe, Cr.	
91.83		1.2	—		
92.25		1.2	—		
93.19		1	1.2	Sharp.	
93.44		1.2	—		
94.21		5	2	Diffuse. Reversed. Cr has 94.20 (3), perhaps divided.	94 03

Cobalt λ	R.	i		**Remarks**	Liveing and Dewar
		Co	⊙		
3895.12		3.4	2		94.93
——	3897.60				
98.64		2	1	⊙ double { 98.55 .65 Co.	
3904.20		2	1		
06.42		3	2		05.83
10.08		3.4	2.3	⊙ close double } 09.98 Fe. 10.08 Co.	09.63
15.66		1	1		
——	3916.88				
17.26		2.3	—	⊙ 17.30 (Fe).	16.83
19.79		1.2	—		
20.28		2	?		
20.89		2	1.2	Very sharp ⊙ triple { 20.75 Fe. .89 Co. .99 Fe.	
21.24		1.2	?		
22.88		2.3	2	Very sharp.	
25.32		1.2	—		
29.42		2	?	Between a fine ⊙ line and a double. Coinc.?	
33.32		1	?		
34.05		2	1.2		
36.12		4	2	⊙ { 35.95 Fe. 36.12 Co.	36.13
——	3937.47				
41.01		2.3	2.3	Also Fe.	
3941.87		3	2		41.53
45.47		3	2		45.53
47.28		1.2	1		
52.47		2	?		
53.05		3.4	2.3		53.04
57.79		1	1.2		
58.06		3	2		58.34
——	3960.43				
61.14		2	?		
69.25		2.3	—		69.44
72.66		2	—	Between two ⊙ lines.	
73.29		2.3	1.2		
74.87		3	2		74.74
75.48		1.2	—		
77.36		1.2	?		
78.80		3	2		
79.03		1.2	—	Diffuse.	
79.65		3	2		79.34
——	3986.90				
87.26		2	?	In the shading of a ⊙ line.	87.74
90.45		2	—	On one side of 90.52 (Fe).	90.84
91.69		2	—		
91.82		2	2		92.04
94.65		1.2	2		
95.45		4.5	2.3	⊙ double } 95.35 .45 Co.	95.33

Cobalt λ	R.	i		REMARKS	Liveing and Dewar
		Co	⊙		
3998.04		4	2.3		97.94
4011.08		1	1.2		
14.12		2	1		
——	4016.58				
19.47		2	1		
21.05		3.4	2.3		
23.54		1.2	2		
27.21		3	1.2		
——	4029.80				
35.73		3.4	?	Probably coinc. with ⊙ 35.75.	
40.76		1.2	1.2		
40.96		2	1		
45.53		4	2		
49.43		1.2	?		
4053.08		2.3	1.2		
54.08		2	—		
——	4055.70				
57.10		2	—		
57.36		2	1	Very sharp.	
58.36		2.3	2.3	Very sharp.	
58.75		2.3	1	Very sharp.	
66.52		3	1.2	Very sharp.	
68.72		3	1.2	Very sharp.	
69.70		1.2	—		
76.28		2.3	?	Very sharp.	
76.74		2	—		
77.55		2.3	1		
81.63		1.2	—		
82.76		2.3	1		
——	4083.77				
84.28		1.2	?		
85.74		1.2	1		
86.47		3.4	2		
92.55		4	2	⊙ double { 92.45 .56 Co.	
92.98		2	1		
93.20		2	1		
96.08		2	—	Divided from 96.12 (Fe).	
97.37		2	?		
4104.57		2	?		
04.89		2	1	Very sharp.	
09.83		1	—	Doubtful.	
10.21		2	?		
10.69		4	2.3		
18.92		4.5	3	⊙ double { 18.92 Co 19.02.	
21.47		4.5	3		
——	4121.97				
22.42		2	—		
39.58		2	—		
50.59		2	1.2		
——	4157.95				

Cobalt	R.	i		Remarks	Thalén
λ		Co	⊙		
4158.58		2.3	1.2		
62.33		2.3	2	Double. $\Delta\lambda=0.09$.	
71.02		2	—	Not coincident with 71.07 (Fe).	
——	4185.06				
87.44		2	1		
90.87		3	1.2		
93.01		1	1		
98.01		1	—		
98.58		1.2	—		
4207.77		1.2	—		
10.26		1	?		
15.03		1	1		
——	4215.67				
25.28		1.2	2		
30.15		1	1.2		
——	(4233.40)			*	
34.18		2.3	1		
37.54		1.2	1		
38.63		1.2	1		
41.69		2	1		
42.06		2	?		
45.76		1.2	—	Diffuse.	
48.37		1.2	?		
52.47		3	1.2		
——	4254.50				
60.05		1.2	1		
63.92		1.2	—		
——	4267.96				
68.18		1.2	—		
68.59		2	—		
70.58		1,2	—		
76.25		2	1		
85.93		2.3	1.2	Very sharp.	
92.41		2	1.2	Diffuse.	
——	4293.25				
98.14		1.2	—	Diffuse.	
4303.36		2.3	2		
07.57		2	—		
09.54		2	2		
10.24		1	—		
——	4318.82				
20.53		1.2	1	Diffuse.	
31.38		2.3	—		
39.76		3	—	⊙ has $\left\{\begin{array}{l}39.61\\ \quad .85\end{array}\right.$ Cr. No coincidence.	
40.39		1	—		
——	4343.39				
53.96		1.2	1		
57.05		2	1		
57.33		1	—		
59.60		1.2	1		
60.98		1.2	1.2		
61.20		1	—		

* The solar lines λ 4233.40, 4476.20 and 4530.95 are not in Rowland's list of standard lines, but they have been taken from his map of the solar spectrum.

Cobalt λ	R.	i Co	i ⊙	REMARKS	Thalén
4362.11		1	—		
66.37		1.2	—		
71.27		3	?	Between two strong ⊙ lines.	
73.77		3	2		
74.66		1.2	2		
75.09		2.3	1.2		
75.70		2	?		
——	4376.10				
79.37		1.2	2.3	Perhaps Va. Neighboring Va lines do not occur.	
80.25		3	2	Diffuse.	
88.02		2	2		
91.70		3	1		
92.02		2.3	1		
95.99		2	2		
4402.85		2	1		
——	4407.85				
16.63		1.2	1		
17.55		3	?		
21.48		2.3	?	Sharp.	
31.78		2	—		
——	4435.85				
36.37		1.2	1		
38.05		1	1		
42.13		1	?		
45.21		2	—		
45.88		2.3	—		
——	4456.05				
67.04		3.4	2		
69.72		4	1		
71.70		3	?		
71.96		2	—		
——	(4476.20)				
77.36		1.2	—	Diffuse.	
78.45		3	1		
83.70		2.3	—	Diffuse.	
84.07		2.3	1	Sharp.	
84.65		2	—	Sharp.	
86.89		2	—	Sharp.	
90.46		1.2	—		
92.23		1.2	—		
——	4494.73				
94.92		2.3	—	Sharp.	
99.45		1	—		
4500.71		1	—		
——	4508.46				
14.33		2.3	2		
17.28		3.4	1.2		
19.42		2	—	Diffuse.	
24.88		1.2	1		
25.97		1.2	1	Coinc. ?	
26.94		1.2	—		
28.12		2.3	—		

Cobalt λ	R.	i		REMARKS	Thalén
		Co	⊙		
—	(4530.95)				
4531.14		5	2		31.45
34.18		4	3		
40.96		1.2	?	40.90 Cr.	
43.99		3.4	1		
45.42		2	—	Between two ⊙ lines.	
46.14		2.3	2		
47.06		1.2	?		
49.80		4	3	⊙ { 49.65 .80 } Ti has 49.79; probably divided.	
53.51		1.2	—		
—	4554.21				
62.11		1.2	—		
64.13		1.2	—		
64.35		2	—	Sharp.	
64.98		1.2	?		
65.74		4.5	?	Apparently displaced with reference to the ⊙ line 65.82.	
66.77		2.3	?		
70.18		3	?	Perhaps a ⊙ line.	
73.75		1	—		
75.12		1.2	—		
—	4578.73				
80.32		2.3	—		
81.76		5	?	⊙ strong double { 81.59. .69 Co?	81.75
87.08		1.2	—	Sharp.	
88.86		2	1	Sharp.	
94.75		4	1		
97.02		4	1		
4601.31		2	—		
07.46		2	1.2		
09.08		1.2	—		
—	4611.45				
12.57		1	—	Diffuse.	
14.18		2	?	⊙ has { 14.10 .35 } Co line appears to lie between these two.	
20.96		1.2	—		
22.83		1.2	—		
23.15		2.3	—		
24.70		1.2	—	Perhaps a ⊙ line.	
25.88		3	—		
29.05		2	—		
29.47		4.5	2.3	29.47 Ti.	
40.99		1.2	—		
—	4643.64				
43.92		2	—		
44.48		2.3	1		
45.34		1.2	1.2	45.36 Ti. Co line doubtful; i variable.	
51.28		1.2	—		
52.01		1.2	—		
53.93		1.2	—		

Cobalt λ	R.	i		Remarks	Thalén
		Co	⊙		
4655.01		2	—		
57.56		2.3	1		
63.58		4	?		
68.04		1.2	—		
——	4668.30				
76.91		1.2	—		
77.46		1.2	—		
77.73		1.2	—		
——	4678.35				
80.62		1.2	—	Between two ⊙ lines. No coinc.	
82.53		4	1.2		
86.05		1.2	—		
88.68		1.2	—		
93.37		3.4	—		
97.19		1.2	1.2		
98.60		3	2		
99.35		2	—		
——	4703.99				
4704.57		1.2	—		
18.67		2.3	2		
21.61		1.2	—		
25.44		1	—		
——	4727.63				
27.95		1.2	—		
28.14		3	—		
32.25		1.2	—		
35.04		2.3	—		
37.95		2.3	—		
38.34		1	—		
42.40		1	—	Diffuse. Perhaps double.	
42.76		1	—		
46 31		2	?		
49.89		4.5	1		49.34
——	4754.23				
54.59		3	1		
56.93		2	?		
67.33		2.3	—		
68.26		3	1		
71 27		3.4	1.2		
76.49		3.4	1.2		
78.42		2.3	1.2	78.44 Ti.	
80.14		4	2		79.54
81.62		3	—		
82.76		1.2	—		
——	4783.60				
85.26		2.3	—		
93.03		4	1.2		92.54
96.00		2.3	—		
96.46		2	?		
97.93		1.2	—		
98.01		1.2	—		
——	4805.25				

Cobalt λ	R.	i Co	i ⊙	REMARKS	Thalén
4813.67		4.5	1.2		14.40
14.16		3	?		
16.11		2	1		
18.13		1.2	1		
——	4824.32				
40.42		4.5	2	⊙ double { 40.42 Co. .50 Fe.	39.90
43.61		2.3	1.2		
55.40		1.2	?		
55.86		1	1.2		
——	4859.93				
62.29		1.2	—	Divided from 62.25 Mn.	
63.64		1.2	—		
68.05		5	1.2		67.90
69.59		2	1		
78.53		1.2	—		
80.43		1	—		
82.90		3	?		
87.19		2	1.2	Ni, Co ?	
——	4890.94				
97.36		2	—		
99.72		3	—		
——	4900.10				
4904.37		2.3	—		
07.30		1	—		
07.78		1	—		
08.68		1.2	?		
12.62		1.2	1		
——	4919.18				
20.47		2	—		
25.20		1.2	—		
28.48		3	1.2	Also Ti.	
33.08		1.2	—		
——	4934.25				
35.40		1	—		
36.61		1.2	—		
41.53		1	—		
42.56		1	—		
48.77		1.2	—		
53.37		2	1.2	Ni, Co ?	
——	4957.48				
59.89		1	—		
66.77		2.3	?		
67.72		1	1		
68.09		1.2	2	Diffuse.	
71.22		1 2	—		
72.16		2.3	—		
——	4973.27				
74.75		1.2	?		
80.15		2.3	—		
86.69		1.2	—		
88.15		2.3	?	Double, $\Delta\lambda = 0.16$. Setting on the middle.	

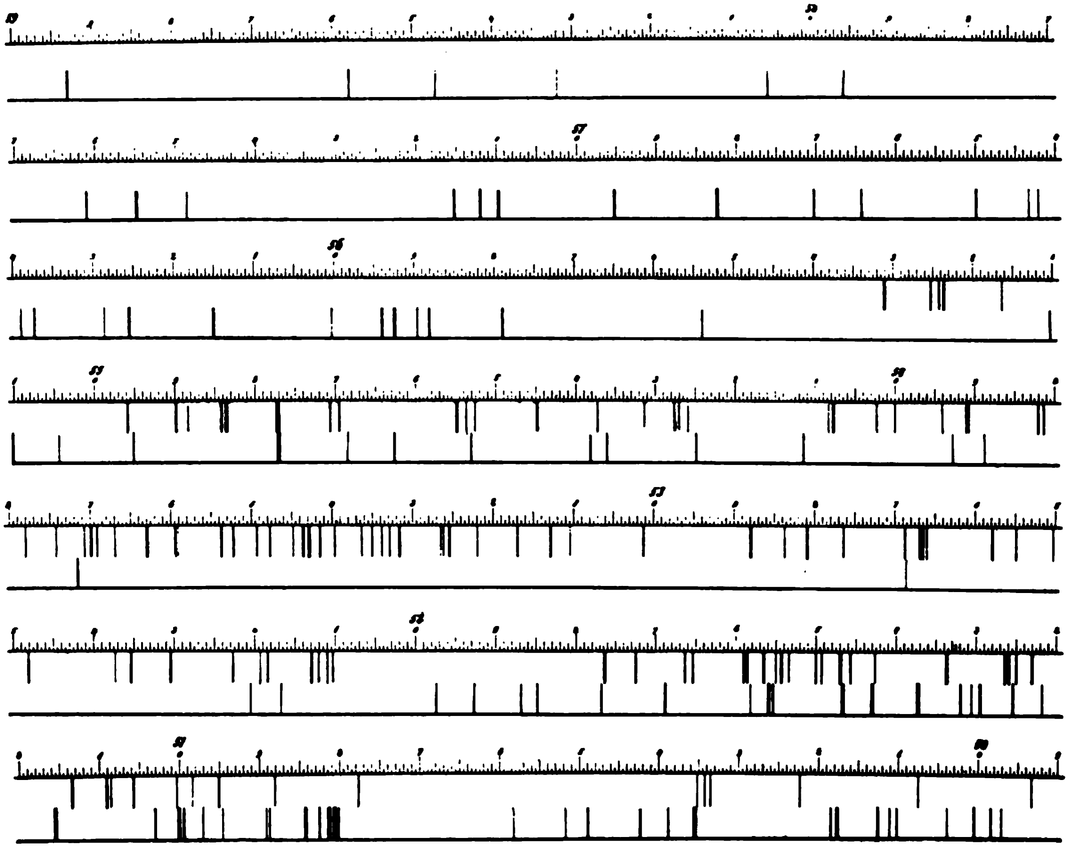
Cobalt λ	R.	i		REMARKS.	Thalén
		Co	⊙		
4993.27		1.2	1		
——	4994.32				
5007.49		1.2	2.3	Coinc. doubtful.	
——	5014.42				
22.37		1.2	2	A faint Fe line divided from Co.	
33.55		1	?		
34.24		1.2	?		
35.16		1	—		
——	5036.11				
77.64		1.2	?	Perhaps a ⊙ line.	
88.08		1.2	?	Perhaps a ⊙ line.	
95.18		2.3	1		
——	5097.18				
5100.30		1.2	—		
05.73		2	2	Int. of Co variable; impurity ?	
08.55		1	1		
09.08		2.3	1		
13.41		2.3	1.2		
——	5115.56				
23.01		2.3	1		
24.99		1.2	?		
25.88		2.3	?		
26.37		2.3	2	Sharp.	
33.65		3	—	Sharp.	
——	5133.87				
42.65		1.2	2.3		
45.73		2	1.2	Diffuse.	
46.96		3	1	No ⊙ line on Rowland's map.	
49.32		1.2	1	Also Mn. No ⊙ line on Rowland's map.	
50.03		2	1		
——	5151.03				
53.43		1.2	1.2		
54.26		2.3	2		
55.04		1.2	—		
56.53		2.3	—		
58.61		2	—	Diffuse } between these lines there	
59.03		2	—	Diffuse } is a faint ⊙ line.	
65.32		2	1	No ⊙ line on Rowland's map.	
66.30		2	—		
72.49		2	?	Diffuse. In the shading of b_2.	
——	5173.91				
76.27		2.3	1	Very sharp.	
——	5188.95				
5210.28		1.2	—	Sharp.	
11.08		1	1		
12.87		2.3	1	Very sharp. ⊙ line distinct.	13.09
——	5217.56				
18.42		2	2		
19.28		1	—		
22.71		1.2	—		
30.38		2.3	1.2	Very sharp.	31.09
35.37		2.3	1	Very sharp.	35.49

Cobalt λ	R.	i		Remarks	Thalén
		Co	⊙		
5237.32		1	—		
——	5242.66				
48.12		2.3	1	⊙ line excessively faint.	
50.21		2	—		
54.83		2	—		
57.81		2.3	1.2		
——	5261.88				
66.00		1.2	2		
66.51		3	1		
66.71		3	3.4		66.79
68.72		2.3	—	Very sharp. Between $\left\{\begin{matrix}68.55\\ .80\end{matrix}\right\}$ Fe	68.79
76.38		2.3	—	⊙ 76.20 = Cr.	
80.85		3	1.2		80.69
83.68		1.2	1.2	⊙ line is a companion to 83.80 (Fe).	
——	5283.80				
87.78		1.2	?		
88.02		1.2	?		
92.45		1	—		
5301.24		2.3	1.2	Very sharp.	
——	5307.55				
10.47		1.2	?	} Only traces of ⊙ lines.	
12.84		2.3	1		
16.96		2.3	2	⊙ line double $\left\{\begin{matrix}16.75\\ .95\end{matrix}\right\}$ The corona line.	
21.95		1.2	—		
25.44		2.3	1		
26.15		2	—		
26.49		1.2	—		
31.65		2.3	1.2	Very sharp.	
32.85		2	2		
——	5333.09				
33.85		2	1		
35.06		2	1.2	Co double.	
36.36		1.2	?		
37.56		1	?		
39.71		2	—		
41.53		2.3	—	Sharp.	
42.86		4	1.2		43.35
43.58		3	2		43.85
44.79		1.2	?		
47.68		2	—		
49.29		2	—		
52.22		2.3	1.2		52.45
53.69		3	1.2	⊙ double $\left\{\begin{matrix}53.59 \text{ Fe.}\\ .69 \text{ Co.}\end{matrix}\right.$	53.65
59.16		1.2	1		
59.41		2.3	1		60.75
——	5361.81				
62.97		3	3	⊙ a close double. Coincidence probable with violet component.	63.75
66.97		1.2	—		

Cobalt λ	R.	i Co	i ⊙	REMARKS	Thalén
5369.13		1.2	—		
69.79		3	1.2	Sharp. Ti has a line at 69.81.	69.25
70.60		1	1		
74.21		1	—		
77.99		1	1.2		
——	5379.78				
81.31		2	2		
81.99		2.3	1		
90.71		1.2	1.2		
91.01		1	—		
94.02		1	—		
——	5397.35				
5400.03		1.2	—		
02.24		2	1		
07.75		2.3	2	⊙ double { Violet component = Mn. Red component = Co.	
08.37		1.2	—		
——	5415.42				
25.87		1.2	—		
27.01		1	—		
27.41		1	—		
27.59		1	—		
31.40		1.2	—		
——	5434.74				
37.25		2	1		
44.81		3.4	1		44.30
52.53		1.2	?		
53.61		1	—		53.30
54.79		3.4	1		
——	5455.76				
69.55		2	—		
70.73		2	—		
77.13		3	3		
——	5477.13				
77.37		2	—		
83.57		4	2		83.70
84.22		3	1		
88.38		1.2	1		
89.90		3	?		
95.94		2	—		
——	5497.73				
5516.29		1.2	—		
23.56		3	1		
24.24		1	1		
25.27		2.3	?		
——	5528.64				
31.06		3.4	1		

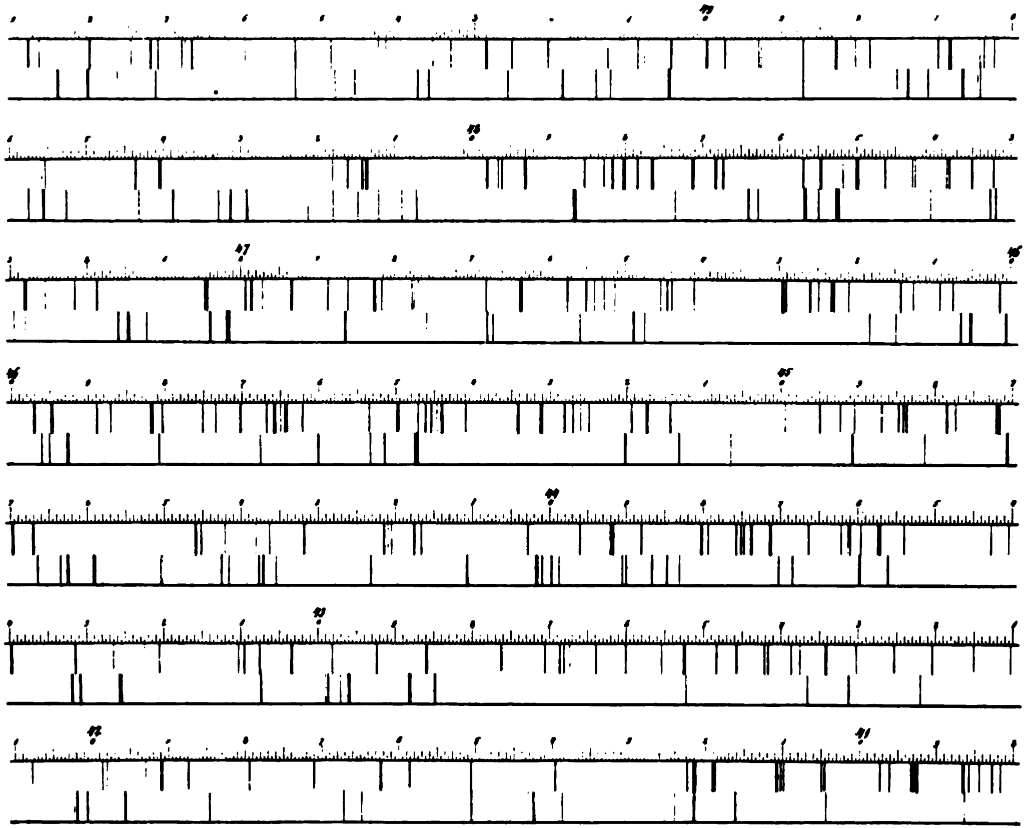
[*To be continued.*]

PLATE XVII.



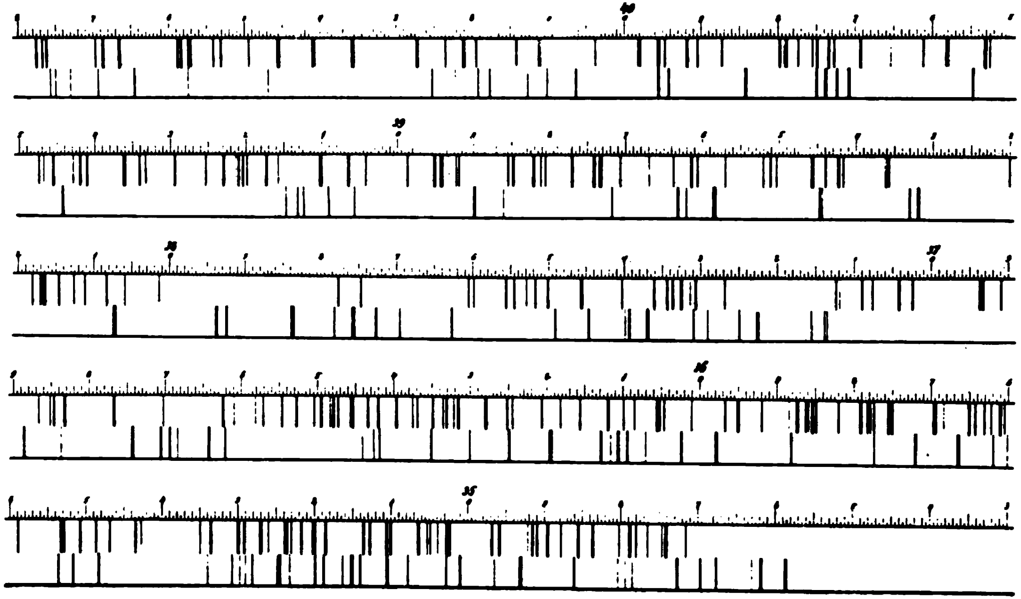
SPECTRA OF COBALT AND NICKEL.

PLATE XVIII.



SPECTRA OF COBALT AND NICKEL,

PLATE XIX.



SPECTRA OF COBALT AND NICKEL.

MINOR CONTRIBUTIONS AND NOTES.

ARMAND HIPPOLYTE LOUIS FIZEAU.

ARMAND HIPPOLYTE LOUIS FIZEAU died on the 18th of September last, having almost completed the seventy-seventh year of his life. His father, a distinguished physician, left him a fortune which enabled him to devote himself to the pursuit of science.

Fizeau's most notable achievement was the determination of the velocity of light in 1849: the first determination independent of astronomical methods, all of which involve a knowledge of the distance of the Sun from the Earth. It is true that his familiar toothed-wheel apparatus has proved less accurate than the more complicated revolving mirror method of Foucault in the hands of modern physicists, but even so lately as in 1874 Cornu preferred it in his very elaborate determination of this physical constant.

Another important question in physics with which Fizeau's name is connected is that of the influence of the motion of the medium through which light waves are moving. Fresnel had been led to the conclusion that a body carries with it in its motion only the excess of ether which it posesses above that of empty space. To test this conclusion Fizeau employed an interferential refractometer devised by himself. By its means he was enabled to pass two beams of light through two adjacent parallel tubes filled with water; then, after reflection, have each beam return by the path previously taken by the other. These two beams were combined at the focal plane of a telescope where the resulting interference bands could be observed. The water in the system of pipes was then set in motion so that one beam of light, both in going towards and returning from the mirror, was moving in the same direction as the water, while the other beam was in the contrary condition. The measured displacement of the interference bands was such as to confirm Fresnel's views.

Other important works were an investigation of the phenomena of interference of light waves when the difference of path differed very greatly, even to the extent of fifty thousand wave-lengths in some cases, and of the dependence of the refractive indices of solids on the temperature. In the latter research Fizeau made the unexpected discovery that in many instances the index increases with rising temperature.

As Fizeau attained to an election into the French Academy in 1860 he has had the rare distinction of being a member for more than thirty-six years.

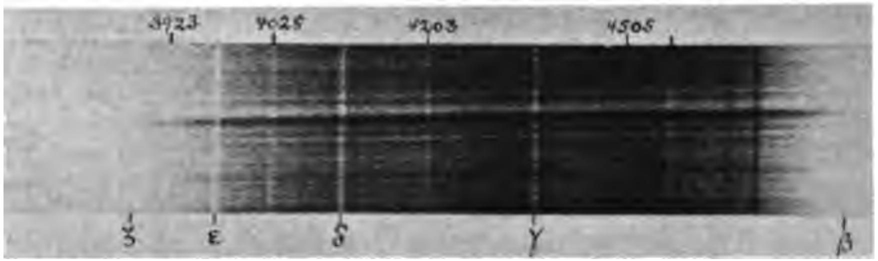
C. S. H.

FRANCOIS FELIX TISSERAND.

Francois Felix Tisserand was born on January 13, 1845, at Nuits-Saint-Georges, in the department of Côte-d'Or. After three creditable years of study in the Ecole Normale Supérieure he was appointed in 1866 assistant astronomer in the Paris Observatory, where Leverrier was then Director. During the succeeding seven years he conducted observational work in various departments of the Observatory, and in a discussion of the Moon's motion, gave evidence of the ability later more fully shown in his great treatise on Celestial Mechanics. In 1868 Tisserand observed the total eclipse of the Sun in Malacca, whither he was accompanied by MM. Stephan and Rayet. In 1873 he was appointed Director of the Toulouse Observatory, where he remained, superintending the execution of many important researches, until 1878, when he was recalled to Paris to occupy posts at the Bureau des Longitudes and the Sorbonne. His occupancy of the chair of Celestial Mechanics, first as associate and later as successor to Puiseux, dates from 1883.

At the death of Admiral Mouchez he was appointed Director of the Paris Observatory. The few years of his administration have been occupied with labors which will add both to his own reputation and to that of the great establishment which was in his care. The last volume of his well-known treatise on Celestial Mechanics was completed only a few months before his death. The important international undertaking of charting the heavens by photography, so successfully inaugurated by his predecessor, Admiral Mouchez, was carried forward by Tisserand with characteristic vigor. Admired by all, both for his scientific ability and his personal qualities, and rejoicing in the full development of his powers, he died suddenly in Paris on October 21, at the age of 51 years. His loss will be universally regretted.

PLATE XX.



SPECTRUM OF ζ PUPPIS.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 12.

STARS HAVING PECULIAR SPECTRA. NEW VARIABLE STARS IN CRUX AND CYGNUS.

A LIST of stars having peculiar spectra and found by Mrs. Fleming in her regular examination of the Draper Memorial photographs are given in the annexed table. The successive columns give the designation of the star, the approximate right ascension and declination for 1900, the catalogue magnitude, and a brief description of the character of the spectrum, followed by additional remarks when required.

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h. m.			
− 39° 3939	8 0.1	− 39° 43	2.5	Peculiar. ζ Puppis. (Plate XX.)
Z.C. 11^h742	11 11.2	− 57 23	9	Type IV.
A.G.C. 15946	11 35.0	− 72 0	8.5	Type IV.
......	12 26.9	− 57 1	..	Type III. Hydrogen lines bright. Variable.
− 36° 11341	17 7.0	− 37 0	9.1	Gaseous Nebula. Gal. long. 317° 12′. lat. − 0° 15′.
A.G.C. 22812	16 47.0	− 42 12	5.8	$H\beta$ bright. ζ^1 Scorpii.
A.G.C. 23694	17 24.1	− 49 47	2.9	$H\beta$ bright. α Aræ.
+ 44° 3649	20 54.4	+ 44 24	7.9	Peculiar.
+ 44° 3679	20 58.9	+ 44 25	6.8	Peculiar.

The spectrum of the first of these stars is very remarkable and unlike any other as yet obtained. The continuous spectrum is traversed by three systems of lines. First, the hydrogen lines and the line K, which are dark, as in stars of the first type. Second, two bright bands or lines whose approximate wave-lengths are 4652 and 4698, which may be identical with the adjacent lines in spectra of the fifth type. Third, a series of lines whose approximate wave-lengths are 3814, 3857, 3923, 4028, 4203 and 4505, the last line being very faint. These six lines form a rhythmical series like that of hydrogen and apparently are due to some element not yet found in other stars or on the Earth. The formula of Balmer will not represent this series, but if we add a constant term and write $\lambda = 4650 \frac{m^2}{m^2 - 4} - 1032$, we obtain for *m* equal to 10, 9, 8, 7, 6, and 5, the wave-lengths 3812, 3858, 3928, 4031, 4199 and 4504. The deviations from the observed wave-lengths have an average value of 3 ten-millionths of a millimeter, are systematic rather than accidental, and although small appear to be rather larger than might be expected from the errors of observation. A line of wave-length 5168 is indicated for $m = 4$, and, if present, could be observed visually, or photographed on a plate stained with erythrosin. The only other line found in the spectrum of this star has the wave-length 4620, and apparently does not belong to this series.

The fourth star in the table is a new variable in the constellation Crux. A comparison with eight adjacent catalogue stars gives its position for 1875, R. A. $= 12^h\ 25^m\ 27^s.5$, Dec. $= -56°\ 53'\ 25''$. The period is about a year. The photographic magnitude, as derived from 57 plates, is 10.3 at maximum, and fainter than 13.2 at minimum.

The fifth of these objects is *N. G. C.* 6302, whose spectrum, on a photograph taken on July 9, 1896, is shown to contain the bright lines characteristic of gaseous nebulæ.

The presence of the bright hydrogen line in the sixth of these objects was found independently by Miss A. J. Cannon.

The last two objects in the table have similar spectra, containing two bright bands resembling, and perhaps identical with, those in the spectrum of ζ Puppis.

In addition to the above objects a star in the constellation Cygnus, whose approximate position for 1900 is R. A. $= 21^h\ 38^m.8$, Dec. $+ 43°\ 8'$, has been found to be variable by Miss Louisa D. Wells. Its period appears to be about 40 days, and its photographic brightness varies from 7.2 to fainter than 11.2, an unusually large range for a variable having so short a period. Its position for 1900, as determined visually by Mr. O. C. Wendell, is R. A. $= 21^h\ 38^m\ 46^s.21$, Dec. $= + 43°\ 7'\ 34''.8$.

EDWARD C. PICKERING.

November 2, 1896.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 13.

RELATIVE MOTION OF THE STARS IN THE LINE OF SIGHT.

THE determination of the motion of the stars in the line of sight by means of the spectroscope is one of the most important problems in astronomy. The greatest, and almost the only, objection to the objective prism is that it has thus far failed to determine this quantity. Placing the prism in front of the objective has many advantages over the use of a slit spectroscope. Instead of photographing one star at a time, more than a thousand have, in many instances, been photographed upon a single plate. In fact, our only knowledge of the photographing spectra of the fainter stars is derived from plates obtained with an objective prism. The wave-lengths of the lines can also generally be determined equally well by either method, since in the spectrum of almost every star numerous lines are present whose wave-lengths have already been accurately determined in the solar spectrum. The wave-lengths of other lines can be better determined differentially from these than directly by a comparison spectrum. Nearly all of the Draper Memorial spectra have been photographed by means of objective prisms. Numerous unsuccessful attempts have been made here, ever since this work was undertaken, to determine with an objective prism the approach and recession of the stars (*Annals* XXVI., p. xx). Among other methods which have been tried may be mentioned the use of an absorbing medium like didymium, the variation in length of the spectra, and the use of a point of reference formed by throwing an auxiliary image of the star into the field by means of a small achromatic prism, or by reflecting prisms. Recently experiments have been made by comparing the corresponding lines in the spectra of different stars with their images taken on another plate without the prism and with the film reversed. A discussion of this method by the writer with Mr. Edward S. King has led to the method described below, which promises to determine accurately the relative motion of two or more stars in the line of sight if they are near enough together to be photographed upon the same plate. Let A and B be two such stars, A being at rest and B approaching with such a velocity that a given line in its spectrum is deviated by the amount d, and let a photograph be taken in such a position that the end of shorter wave-length of the spectrum of B is turned towards that of A. Than the distance between the images of the given line in the two spectra will be less by the amount d, than it would be if both stars were at rest. Now let another photograph be taken in which, by turning the prism 180°, the spectra are turned by the same amount, so that the end of greater wave-length of the spectrum of B is turned towards that of A. The distance between the two lines will then be increased by an equal amount. If two such photographs are superposed and the images of the reference line in the spectra of *A* are made to coincide, its images in the spectra of *B* will deviate by $2d$. To apply this method, a photograph of a region a little east of the meridian is taken in the usual way. Then the telescope is reversed and a second photograph of the same region is taken on a plate with the film side away from the star, so that the photograph is taken through the glass. As both photographs are taken near the meridian the lines will be nearly perpendicular to the length of the spectrum, while, at a large hour angle, if the exposure is long, and the spectra narrow, the lines will cross them obliquely, owing to the differential refraction. Reversing the telescope turns the prisms, and with them the spectra exactly 180°. In making the examination the plates are placed film to film so that the spectra are side by side, and one is moved over the other by means of a micrometer screw. The corresponding lines in the two images of each star in turn are made to coincide, and the difference in the readings gives double the displacement of the line. An error in orienting the plates would affect the results when the stars compared are not in the same right ascension. This source of error may probably be made insensible in several ways, such as by marking a reference line on each plate, or by turning the prisms so that their edges are perpendicular to the line connecting the stars and moving the plate slowly by clock-work. Since the ends only of the lines are compared, narrow spectra may be used, and faint stars may therefore be measured. Experiments are now in progress with a cylindrical lens, by which it is expected that the accuracy of setting on lines in very narrow spectra can be still further increased.

Only preliminary tests of this method can be made at Cambridge at present, as our three best prisms are now in Peru. Two photographs of 101 and 102 Herculis were, however, taken on October 9, 1896, with a single prism, giving poor definition, but showed by inspection that the first of these stars was approaching more rapidly than the second. Measures by Mr. King of the lines $H\epsilon$ and $H\zeta$ indicated the relative velocities 87 and 94 kilometers a second respectively. These results are not corrected for the position of the prism and other sources of instrumental error. The probable error as indicated by the accordance of the individual settings is 5 kilometers in each case. An inspection of two photographs of the Pleiades shows that the relative motions of the seven brightest stars in the group, although perhaps measurable is not appreciable to the eye, and probably does not exceed 30 kilometers a second.

The advantages of the above method are, first, the directness of the determination of the motion; second, that double the deviation is measured; and third, that as the ends of two similar lines are made to coincide, the accidental errors of measurement are much less than when each in turn is bisected by a spider line. Since each line in the spectrum may be used a large number of independent determinations may be obtained from one pair of plates. On the other hand, as it is only necessary that one line should be in focus, a visual telescope may be employed; that is, one uncorrected for the photographic rays. No corrections need be applied for the motion of the Sun in space or of the Earth in its orbit, since they will affect both stars equally.

EDWARD C. PICKERING.

November 4, 1896.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 14.

A NEW SPECTROSCOPIC BINARY IN PUPPIS.

AN examination of the Draper Memorial photographs taken at the Arequipa Station shows that the star Lacaille 3105, *Argentine General Catalogue* 10534, is a spectroscopic binary. The approximate position of this star for 1900 is R. A. $=7^h$ 55.3, Dec. $=-48°$ 58′. Its photometric magnitude is 4.50. The lines in its spectrum were first noticed to be double and its binary character discovered by the writer in February 1895. Professor Bailey was notified and accordingly secured additional photographs and confirmed the binary character of this star. As in the case of μ^1 Scorpii one component is brighter than the other. A discussion of all the photographs of its spectrum here and at Arequipa gives the mean period $3^d\ 2^h\ 46^m$. The times of inferior conjunction can be represented by the formula *J. D.* $2412777.16 + 3.115\ E$. At these times the lines are single, for the next thirty-seven hours the lines are double, the fainter component of each having a greater wave-length than the brighter component, and being, therefore, towards the red end of the spectrum. The lines then again become single, and after that, for the remainder of the period are again double, the fainter components having shorter wave-lengths, and being, therefore, towards the violet end of the spectrum.

This is the fourth spectroscopic binary of this class in which both components are bright, the others being ζ Ursa Majoris, β Aurigae and μ^1 Scorpii.

EDWARD C. PICKERING.

November 17, 1896.

ERRATA.

In this JOURNAL, 4, 176, Rowland's and Michelson's wave-lengths of the cadmium lines should have been given as follows:

Rowland's values of the wave-length of the cadmium lines, *reduced to 20° centigrade*, are 6438.680, 5086.001, 4800.097.

Michelson's values of the wave-length of the cadmium lines, *reduced to 20° centigrade*, are 6438.472, 5085.824, 4799.9107.

J. F. MOHLER.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

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The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

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